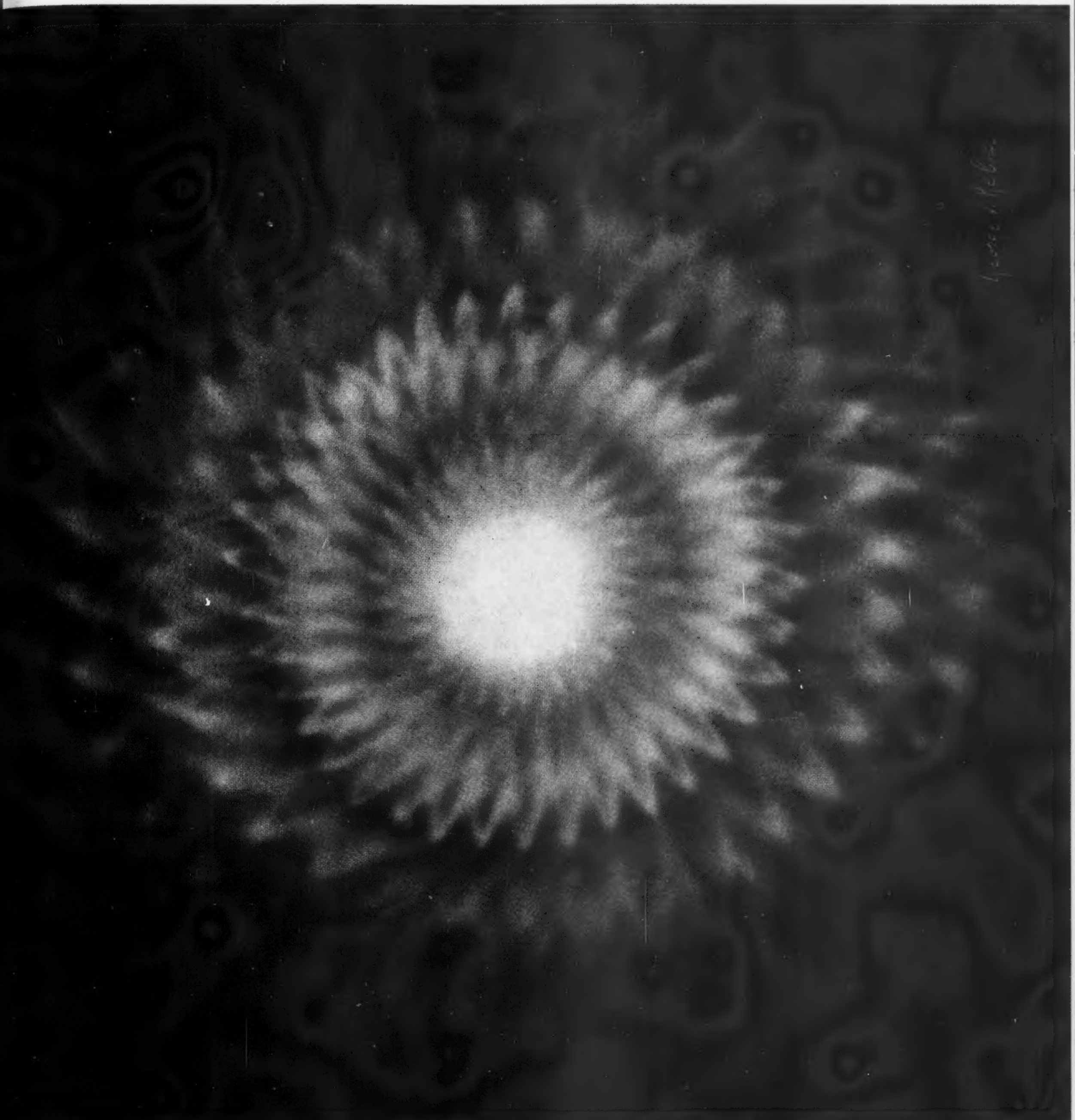
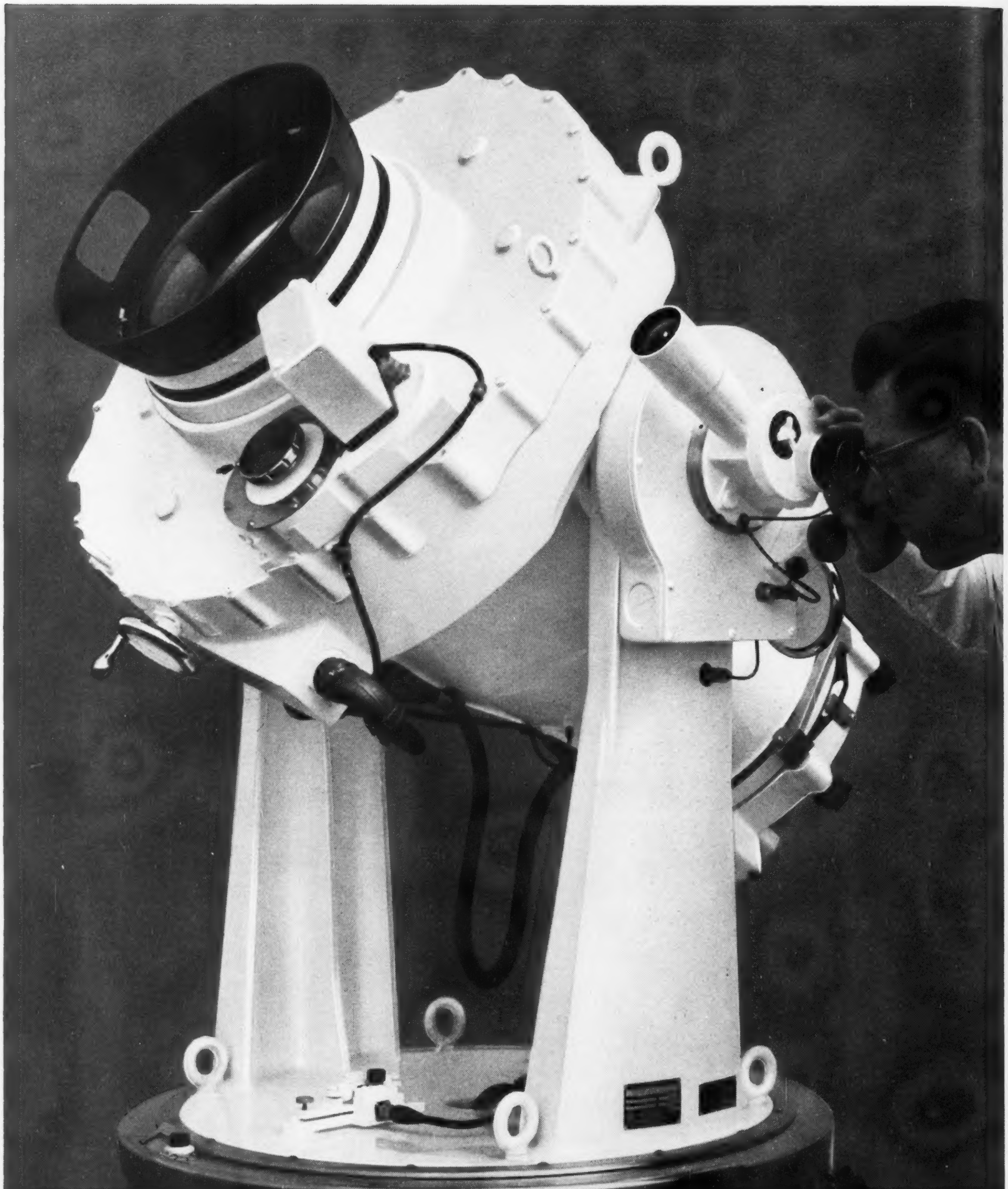
Astronautics

A PUBLICATION OF THE AMERICAN ROCKET SOCIETY

NOVEMBER 1961



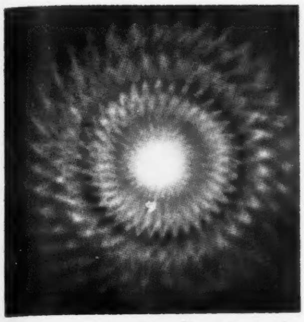
GUIDANCE AND CONTROL ISSUE



This camera watches the birdie

This is a ballistic camera, designed to photograph a missile in flight, and check its trajectory against a precise background of stars to detect the slightest deviation from course. It is the largest accurate ballistic camera ever built. Its 8-element, 600-mm, f/2 lens has an accuracy of 1 part in 200,000. Though the shutter is 12 inches in diameter, it opens and closes in 2 milliseconds. The entire instrument, including its unique lens and shutter, was designed and manufactured by the Nortronics Division of Northrop.

NORTHROP



COVER: "Solar Flare," an impression in glowing color by New York artist George V. Kelvin. (ASTRO cover plaques 11 x 12 in. are available from ARS Headquarters at $2.00 each.)

Astronautics

A PUBLICATION OF THE AMERICAN ROCKET SOCIETY INC.

Vol. 6 No. 11 November 1961

EDITORIAL

GUIDANCE AND CONTROL

ARS NEWS

DEPARTMENTS

EDITOR Irwin Hersey
MANAGING EDITOR John Newbauer
ASSOCIATE EDITOR Stanley Beitler
ART DIRECTOR John Culin
CONSULTING EDITORS Eberhardt Rechtin, George C. Szego
WASHINGTON CORRESPONDENT Henry Simmons
DIRECTOR OF MARKETING Owen A. Kean

BPEA

Published monthly by the American Rocket Society, Inc., and American Interplanetary Society, Inc., at 20th & Northampton Sts., Easton, Pa. Editorial offices: 500 Fifth Ave., N. Y. 36, N. Y. Subscription price: $9, foreign $9.50 per year. Single copies, $1.50. Second-class postage paid at Easton, Pa., with additional entry at New York, N. Y.

Astro notes

MAN IN SPACE

• NASA's Mercury-Atlas 5 carrying a chimpanzee should be launched this month in a three-orbit dress rehearsal for the first U.S. manned orbital mission, hopefully to be conducted before the end of the year. MA-5 will test advanced features of the Mercury spacecraft that were omitted from the successful MA-4 test in September. These include the inflatable landing bag, the trapezoidal "picture window," and a modification of the explosive-actuated escape hatch which malfunctioned during Astronaut Virgil Grissom's MR-4 flight in July.

• Post-flight study of the MA-4 flight was particularly satisfying to officials of the NASA Space Task Group. Principal malfunctions recorded during the flight included excessive oxygen consumption, caused by a vibrating bleed valve especially rigged for the "artificial astronaut," loss of the voice of the artificial astronaut when a tape reel jammed, and failure of an inverter powering a fan. The first problem would not have arisen on a manned flight; the second could have been remedied by a live astronaut; and the third was remedied on the spot by a backup inverter.

• For the record, MA-4 achieved a perigee of 100 mi., an apogee of 158.6 mi., and an orbital flight time of 84 min. Orbital flight was terminated over Guaymas, Mex., when the automatic timer ignited the retrorockets. The capsule landed 161 mi. east of Bermuda after a total flight time of 109 min., with pickup accomplished by a destroyer. Sensors in the capsule showed a maximum launch acceleration of 7.6 g and a deceleration peak of 7.8 g, or substantially less than the peak loads imposed during the steeper re-entry of the Redstone-boosted capsules.

• Cosmonaut Gherman Titov suffered from vertigo sickness during most of his 25-hr orbital flight, according to Vladimir I. Yazdovsky in a paper delivered at the XII International Astronautics Congress held in Washington, D.C. The Soviet physician disclosed that, "Under weightlessness, unpleasant sensations of the vestibular character were felt with increasing strength, especially when the astronaut turned his head sharply or was observing some swiftly moving objects." The sensation diminished after Titov's sleeping period but did not wholly disappear until he encountered deceleration force during re-entry.

• Titov's illness during weightlessness did not affect his ability to carry out his program; but its prolonged nature immediately stimulated speculation concerning means of avoiding it. Proposals, which have been heard before, included drugs to combat motion sickness, surgical alteration of the labyrinthine structures of the inner ear, and artificial gravity by rotation of the spacecraft.

• Care will be exercised concerning such proposals. The first two advance a more drastic violation of the astronaut's physiology than simple body sensors, and the third would require a great complication of spacecraft design—the "merry-go-round" in space, as it has been termed deprecatingly.

• It may well be that some individuals are more sensitive to weightlessness than others. Prof. Yazdovsky stressed this point. It would be jumping to a conclusion to suppose that any of these proposals need be given actuality. The performance of the U.S. astronauts, more mature and experienced pilots than the Russian cosmonauts, will set a better guide, it would seem, in choosing means to avert performance degradation from weightlessness than Titov's responses. The extensive training of the U.S. astronauts could show very well in their response to weightless flight. In any event, everyone from the journalists to the guidance-system designers have their attention fixed on this human factor, which can swing the course of the manned space-flight program.

• While the ARS Space Flight Report to the Nation took place, Maj. Robert M. White piloted the experimental X-15 rocket-powered aircraft to a new altitude record of 215,000 ft and a new speed record of 3647 mph, eclipsing its previous marks for manned winged craft of 169,500 ft and 3645 mph. The X-15 experienced a maximum skin temperature of 900 F during reentry. Its only malfunction was a cracked outer windshield. The following week NASA's Joe Walker piloted the X-15 to a new speed record of 3920 mph; the X-15 skin temperatures reached 1110 F.

• The Air Force has trained its sights on the X-15 as an ideal flight-training vehicle for fledgling Dynasoar test pilots. If Milton Caniff's recent cartoon sequence on "Project Hardnose" didn't spread the word to everyone, the Air Force Association managed to do so at its fall meeting in Philadelphia. USAF officials disclosed that a six-man experimental Space Research Pilots Course was established at the Aerospace Research Pilot School in June. Training with modified Northrop T-38 and Lockheed F-104 jets, the experimental group will develop a syllabus for a 10-man class to commence next June. The jet planes will be equipped with rocket boosters and reaction controls to give students the feel of space operations; but the airmen would like to take the X-15 as a more-realistic trainer.

SPACE ORGANIZATION

• NASA Administrator James Webb abolished the Office of Space Flight Programs and assigned its director, Abe Silverstein, as director of the NASA Lewis Research Center, Cleveland, Ohio; also abolished were the Office of Launch Vehicle Programs and the Office of Life Sciences, whose functions will be assumed principally by D. Brainerd Holmes' Office of Manned Space Flight Programs.

• Other changes include creation of the Office of Space Sciences to be directed by Homer E. Newell, the Office of Advanced Research Programs headed by Ira H. Abbott, and a new Office of Applications (director to be announced) to assume direction of communication and meteorological satellite activities.

• Thomas Dixon, named originally to head the defunct Office of Launch Vehicle Programs, was appointed deputy associate administrator under Dr. Seamans. He will assist in the direction of the research centers and will have personal responsibility for all launch vehicles up to Saturn size. Vehicles of the Saturn class and larger will be handled by Holmes.

• Keeping pace with its administrative shakeup, NASA continued

to expand its facilities for the lunar program. It announced selection of a 1000-acre site near Houston, Tex., for construction of its Manned Space Flight Laboratory and named as director Robert R. Gilruth, present head of the Mercury project. Principal buildings to be constructed for the $60-million "command center" for the lunar expedition include an 8-story administration building, a flight operations facility for training activities, an equipment-evaluation laboratory, and an environmental-testing laboratory.

• An important attraction of the Houston site, donated by Rice Univ., was its direct access to the Gulf of Mexico via a salt-water canal, NASA said. Also a strong factor in its selection was Rep. Albert Thomas, (D., Tex.), who represents the Houston district and who serves as chairman of the House Independent Offices Appropriation Subcommittee, which is responsible for NASA's annual budget.

• The succession of Rep. George P. Miller (D., Calif.) to chairmanship of the House Science and Astronautics Committee was expected to produce major changes in the Committee's attack on space problems. Unlike former Chairman Overton Brooks, who died in mid-September, Rep. Miller was reportedly willing to give greater rein to his subcommittees to hold independent hearings and to place greater reliance upon the technical staff for interrogation.

SPACE VEHICLES

• The Large Launch Vehicles Planning Group reviewing the proposed Nova moon-rocket program has been veering away from the notion of a single huge Nova for a direct earth-moon-earth journey. The planning group, headed by Nicholas Golovin of NASA, has not yet formed a final recommendation, but there were signs that the group was skeptical that a rocket of this size could be developed and "man-rated" in time for a lunar expedition during this decade. If liquid, such a booster would require eight F-1 engines aggregating 12-million-lb thrust; if solid, the booster would require a cluster of solid motors totaling 20-million-lb thrust.

• In place of the direct journey, the Golovin planning group was leaning toward a "half-size" Nova vehicle which could assemble a sufficient spacecraft in earth orbit by means of one or more rendezvous operations. The liquid version of this vehicle might be the "original" Nova, that is, the four-engine rocket of 6-million-lb thrust originally conceived to land a single astronaut on the moon and return him to earth. The smaller size, lower cost, and earlier availability of "advanced Saturns" or "Nova Juniors" are important points in their favor, but at least as significant is a growing realization that the nation which can rendezvous early and often in space will have a paramount advantage in future manned space-flight operations.

• Top-level support for the rendezvous plan based on a four-engine Nova (or Saturn C-4) came from NASA Administrator James Webb and NASA-Marshall Director Wernher von Braun at the ARS Space Flight Report to the Nation in New York. A single rendezvous by two of these vehicles could assemble a 400,000-lb payload in an earth orbit and permit the lunar mission perhaps as much as two years ahead of the direct journey with the full-scale Nova, they said. Three successful rendezvous maneuvers would have to be conducted using the Saturn C-3, tending to rule that out as the principal lunar-mission rocket, even though it could be available six months earlier than the C-4.

• NASA is presently conducting rendezvous studies looking toward a series of flight tests and an orbital docking mission in 1964, probably with the Agena-B vehicle. Some explicit decisions concerning rendezvous are expected from NASA by the end of the year.

• Although Saturn C-4 will likely be used for rendezvous, giant solid rockets, up to 340 in. in diam, will be studied as possible replacements for liquids. Moreover, design studies on direct-flight systems will proceed, despite the new emphasis on rendezvous.

• An interesting NASA study concerns lunar orbital rendezvous with a one-man shuttle vehicle to the lunar surface. This kind of operation would ease demands on the astronaut during landing and take-off. The earth-return capsule would remain in orbit around the moon.

PROPULSION

• NASA set November 8 as the deadline for contractors to submit proposals for developing the advanced Saturn booster, designated S-IB. The booster is sized to accommodate either two or four F-1 engines at a thrust level of 3 or 6 million lb. The contractor selected by NASA, hopefully in December, will participate in the design and development of the rocket stage, produce it at the former Michoud Ordnance Plant, and conduct test activities. Invitations to propose on the S-IB were extended to the same 27 companies which obtained Requests for Proposals on the S-I stage of the Saturn.

• Deadline for proposals on the S-I stage of Saturn, to be powered by eight Rocketdyne H-1 engines aggregating 1.5-million-lb thrust, was set at October 16, with a contractor to be selected for negotiations in November. The S-I stage will be manufactured at Michoud by a different contractor than the one selected for the S-IB, according to NASA sources.

• The Space and Information Systems Div. of North American Aviation was selected to develop and produce the S-II upper stage of the Saturn, which will be powered by four Rocketdyne J-2 lox-liquid hydrogen engines totaling 800,000-lb thrust. The S-II will be used as the second stage of the C-3 Saturn, which will utilize the new S-IB booster. Initially planned to be 21.5 ft in diam, the S-II may be re-sized to approximate more closely the 33-ft diam of the S-IB. NASA will negotiate a contract with NAA for a 10-vehicle S-II development program at an estimated cost of $140 million.

• The Russians, too, appeared to be moving ahead with a larger booster program of their own. On a timetable about two months ahead of NASA's plan for the initial flight test of the Saturn S-I stage, the Russians conducted over a half-dozen long-range booster tests into a 60,000-sq mi. impact area south of Johnston Island. One expert at the XII International Astronautics Congress in Washington, D.C., put the thrust rating of the Russian booster at 1.75-million lb, derived from a cluster of four 440,000-lb-thrust engines.

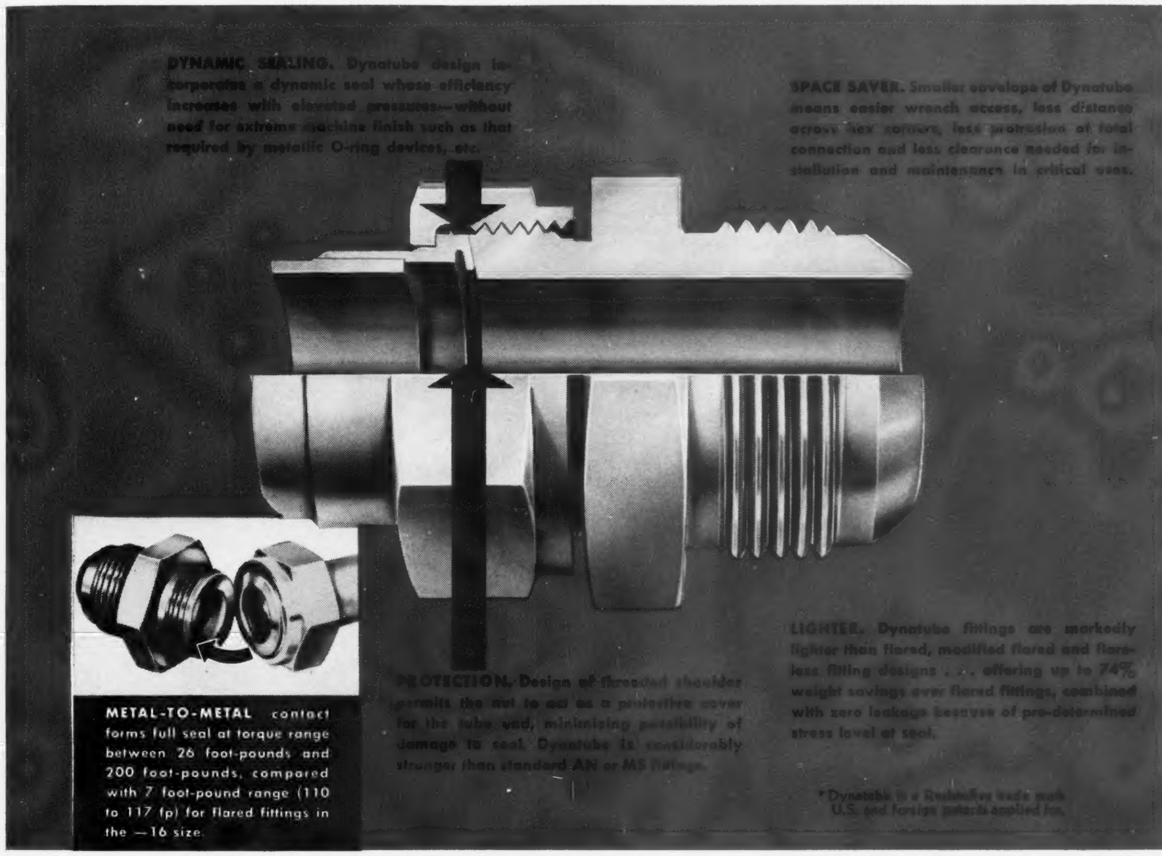
• The Russians said only that their Pacific test series was designed "to test more powerful and improved versions of multistage carrier rockets of space vehicles . . . minus their final stages." Nevertheless, there

(CONTINUED ON PAGE 10)

Leakproof Coupling
for High-Performance Systems

DYNATUBE*

A NEW DYNAMICALLY SEALED TUBE CONNECTION BY RESISTOFLEX



Dynatube, another *first* by Resistoflex, is an all-new concept in metal rigid tube connections . . . providing a superior seal for high performance hydraulic, pneumatic, fuel and oxidizer systems.

Dynatube provides maximum performance because

- The seal is controlled by precision dimensions built into the fitting
- The fitting design is based on pre-determined stress level at the sealing point
- Torque range is extremely wide

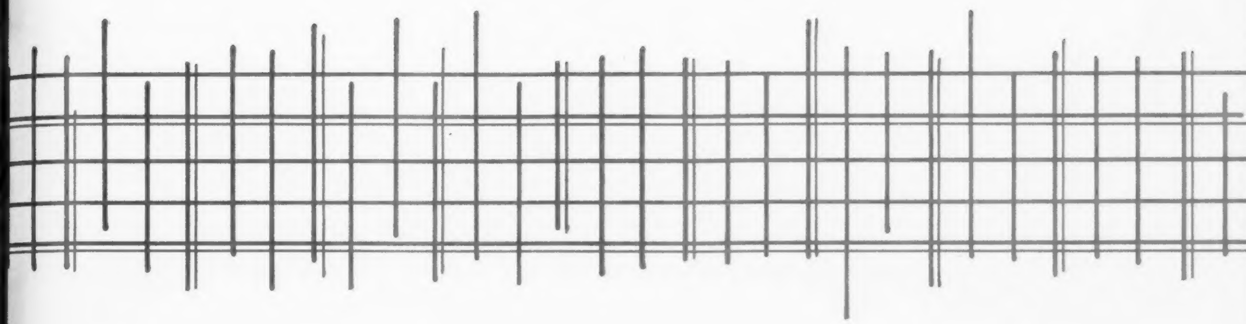
Dependence on surface finishes of sealing seats, concentricity of AN and MS screw machine parts and torque application is completely eliminated with Dynatube.

Severe temperature cycling does not affect the Dynatube seal, which maintains its reliability up to 700° F. and higher, depending on application. Not sensitive to torque degradation, Dynatube has a smaller envelope and is lighter and stronger than corresponding AN or MS fittings. Meets or exceeds all performance requirements of proposed MIL-F-18280B.

Here is the answer to your tube sealing problems. Ask your Resistoflex field engineer about Dynatube, or write to Resistoflex, Roseland, N. J. for Bulletin DY-1.

RESISTOFLEX
RELIABILITY

COMPLETE SYSTEMS FOR CORROSIVE SERVICE



were signs that the Russians may have out-stripped the first Saturn booster already.

• One of the strongest of these signs has been supplied by President Kennedy himself. In a press conference last April, presumably armed with intelligence information, the President said somberly: "Saturn is still going to put us well behind. Saturn does not offer any hope of being first to the moon. Saturn is several years behind the Soviet Union, and I can just say to you that regardless of how much money we spend on Saturn, we are still going to be second." Shortly thereafter, the President announced the nation's lunar-landing program based on the mammoth Nova rocket concept. His remarks did not take account of the possibility of using the Saturn C-4 and rendezvous.

• Republic Aviation unveiled an advanced version of its magnetic pinch-plasma engine, which uses nitrogen as propellant, in a public demonstration. This engine can provide a specific impulse ranging from 1000 to 7000 lb-sec, according to Republic's chief of this development, Alfred E. Kunen. Dr. Kunen said the company will have a "flyable" model of the pulsed engine ready early next year.

• About the same time, Hughes Aircraft demonstrated its cesium-ion engine, which has been selected for an initial flight test late next year as part of a NASA Scout payload.

• Still a third electrical engine, GE's pulsed plasma device, Reppac III, was reported to have operated continuously for 60 hr in a 13-ft vacuum chamber at a thrust rating of 20 millipounds and an impulse of 5000 sec.

• As people in electrical propulsion know only too painfully, the major hurdle to advanced missions with electrical engines will be development of high-power, high-density energy sources. Action in this area, which received the attention of rocket planners five years ago, has finally been taken by the AEC.

• At the SFRN, the AF's Lt. Col. G. M. Anderson, attached to the AEC's Aircraft Nuclear Power Office, and long a sympathetic listener to pleaders for advanced nuclear-electric systems, said the AEC—its new head, Glenn C. Seaborg and the Joint Committee—were solidly behind a program to develop nuclear-electric generators covering the range 100 kw to 10 megawatts.

• During the past administration, conservative elements in the AEC saw little use for such power in space reactors. According to Col. Anderson, "The electrical propulsion boys broke the dam." AEC has moved on the 300-kw Spur program, and was expected to have the first complete *paper* study for Spur on its desk by mid-October.

• The ambitious electrical-propulsion "boys"—they have the spirit of the old rocketeers—are moving toward studies of routine fast flights with large payloads to the planets. Nova may find its justification, Ernst Stuhlinger of NASA-Marshall remarked cheerfully at the SFRN, in such missions.

• The development phasing of adequate power sources for electrical propulsion units may push mission planners to consider high-energy chemical rockets, for example, fluorine-burning, for probes to Jupiter and out of the plane of the ecliptic.

SPACE TECHNOLOGY

• Among several other companies, General Motors has undertaken an extensive research program on mobile lunar vehicles. The company disclosed three different types of lunar vehicle capable of negotiating a variety of lunar terrains: A three-axle vehicle with large doughnut wheels for irregular ground, a tracked vehicle for either soft or hard soil, and an "Archimedes Screw" vehicle which can bore through loose or fluffy soil. The models have been under study for the past year in soil bins placed in vacuum chambers to assess their mobility under a variety of theoretical lunar conditions.

• Despite Soviet criticism, the U.S. went ahead with plans to orbit approximately 75-million hair-like copper dipoles in conjunction with the test launching of a Midas early-warning satellite. Prior to the scheduled launch, the White House made public the report of a special panel of the President's Science Advisory Committee which stated that all the dipoles will be returned to earth within eight years and that the belt, at its maximum power some 60 days after launch, will offer only sporadic and weak interference to radio, optical astronomers.

• North American Aviation was the top recipient of NASA contract awards in fiscal 1961 with a net of $75 million. Following in order were McDonnell Aircraft, $41.8 million; Douglas Aircraft, $30.7 million; Western Electric, $26.6 million; Space Technology Laboratories, $13.1 million; and Chrysler Corp., $12.9 million.

• General Electric abandoned its effort to participate with U.S. common carriers in the formation of a joint venture to own and operate a commercial communications satellite program. In a letter to the Federal Communications Commission, GE Vice-President George Haller formally withdrew the application of GE's subsidiary, Communication Satellites, Inc., and announced that the company was dissolved. He added that GE is still anxious to supply equipment for any commercial satellite system finally approved by FCC.

• Looking toward a Saturn launching schedule of 32 vehicles a year by the mid-sixties, NASA Launch Operations Director Kurt Debus has prepared plans for a radically new type of complex eliminating the costly movable assembly tower and reducing to a minimum the launch complex itself. Described by Dr. Debus at the SFRN, it would utilize a vertical assembly and checkout building and relatively simple transport and arming towers to haul the missile to the pad. Debus told the ARS in New York that the proposed complex would cost $190 million, but would easily save that much in the long run. Reliance on the present Saturn movable tower and blockhouse principal would mean a total requirement for eight separate Saturn complexes at a total cost of $360 million to handle the projected launching load.

SATELLITES

• The embarrassing growth of satellite payloads is not a problem peculiar to U.S. space engineers. The same trouble plagues British engineers working on the United Kingdom's solar-powered ionosphere satellite. This has climbed to 128 lb, too heavy to be placed in a 200 to 600 mi. orbit by the Scout vehicle. NASA has consequently ordered a switch to the Thor-Delta booster.

• AF snatched the re-entry capsule of Discoverer XXX from the air after 33 earth orbits, but it failed to recover Discoverer XXXI when the capsule refused to separate from the Agena-B stage. Its record stood at eight capsule recoveries—five in the air and three from the sea. The Discoverer XXX capsule

carried spores, tissues, and cells to study the effects of solar and cosmic radiation, a nuclear emulsion block to record the passage of energetic particles, and samples of a variety of sensors to detect the energy, intensity, and nature of energetic particles encountered.

• At the SFRN, James Van Allen gave the latest estimate of omnidirectional electron density, J_o, in the heart of the outer radiation belt, based on Explorer XII readings on September 5, as follows: $J_o > 40$ kev, $10^8/\text{cm}^2/\text{sec}$; $J_o > 2$ mev, $10^5/\text{cm}^2/\text{sec}$; and $J_o > 5$ mev, $10^2/\text{cm}^2/\text{sec}$.

MISSILES

• Defense Secretary Robert McNamara has recommended expansion of the Minuteman ICBM and Polaris missile-submarine programs as part of a proposed five-year Pentagon development and procurement plan. Principal elements of the plan include expansion of the Minuteman ICBM program from 600 underground weapons to a new total of 900, increasing the Polaris submarine force from 29 to 41 vessels, and additional procurement of the Convair F-106 interceptor for air defense and the Douglas A4D-5 to support the newly integrated USAF Tactical Air Command and the Army's Strategic Army Corps. No additional purchases of the B-52 bomber were recommended, and an acceleration of the B-70 program was overruled despite Congressional appropriations for these programs.

• AF has placed the second element of its Ballistic Missile Early Warning System (BMEWS) into full operation at Clear, Alaska. It follows by a year introduction of the initial BMEWS radar complex into operational status at Thule, Greenland. The third station, Flyingsdale, Yorkshire, England, has fallen behind schedule because of labor difficulties, but it is still expected to be completed next year.

• The Martin Co. successfully raised a Titan I missile from a 165-ft steel-and-concrete silo at Vandenberg AFB and fired it 4500 mi. to an impact point near Wake Island. The mission was the last hurdle between the Titan I and operational status. The first Titan squadron will become operational with the Strategic Air Command at Lowry AFB, Colorado, by the end of the year.

VENUS

• The sharp disagreement between Soviet and U.S. radar measurements of the Astronomical Unit (mean distance from sun to earth) was resolved at IAF Congress in Washington, D.C., but Soviet scientists are still at odds with their U.S. colleagues on the question of the rotation of Venus. The USSR initially announced an AU value of 149,457,000 km last spring, considerably below the Jet Propulsion Laboratory measurement of 149,598,820 km, and the MIT Lincoln Lab's value of 149,597,850 km. The new Russian figure was put at 149,599,500 km by V. A. Kotelnikov, who gave a report in a joint session with JPL and MIT scientists at the Congress. Dr. Kotelnikov did not explain the initial discrepancy, but U.S. scientists believe that the early reduction of the Soviet results contained an ambiguity and that the Russians simply picked the wrong number for their analysis.

• On the question of the rotation of Venus, Dr. Kotelnikov repeated the earlier deduction of his group that the planet rotates at least once every 11 days, and perhaps slightly faster if the axis is inclined as much as 60 deg. U.S. radar astronomers disagreed. They reported that the planet probably does not rotate more rapidly than its sidereal rate of 225 days. The Lincoln Lab's group believes that the planet is at least three times smoother than the moon as a radar target, based on negligible "broadening" of the echo ascribed to Doppler effect. The U.S. radar experts have attempted to interpret specular elements of the planet. The Russians assume a "diffuse" signal from the whole planetary disk.

• Continued delays in the Centaur development program have forced a drastic reduction in the size of the U.S. Venus probe to be launched during the August 1962 "window," and they have killed chances that the U.S. might launch a Mars probe a year from now. The Venus probe should provide a key to several proposed models of the Venusian atmosphere and surface.

• In place of the planned Venus probe, the 1150-lb Mariner A, JPL will prepare a bobtailed Mariner-R weighing 400 lb and based on the Ranger lunar spacecraft. Mariner-R will carry the usual panoply of radiation, magnetic-field and micrometeoroid experiments plus a single pointed experiment—a radiometer to scan the surface of Venus to map temperature distribution. While the Atlas Agena-B will be able to inject the 400-lb payload on a Venus trajectory, it will not be able to manage sufficient weight for a Mars transit. The full-sized Mariner will not have its first launch opportunity until 1964.

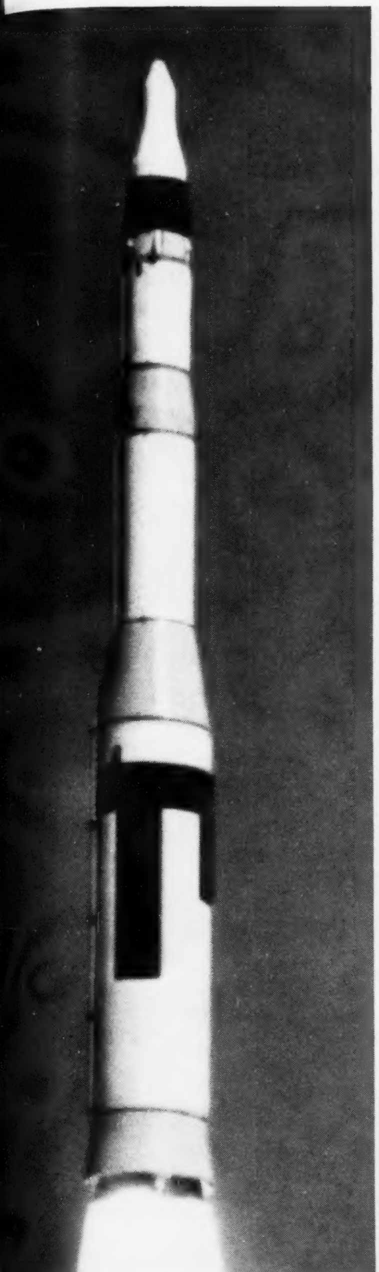
• The various studies of Venus to date make it seem unlikely that this planet harbors life. It is to Mars that the scientists look with real expectation of finding extraterrestrial life. The loss of a chance at a Mars flight next year thus comes as a great disappointment to U.S. scientists, and offers a great opportunity to the Russians. For the finding of living organisms on the Red Planet will swing the scientific community toward a revolutionary epoch of panstellar exploration, already presaged in the Ozma experiment by Frank Drake and his associates at the National Radio Astronomy Observatory.

• As Phillip Morrison of Cornell Univ.'s Laboratory of Nuclear Studies said at the SFRN Global Effects symposium, in conclusion to his brilliant exposition of theory and experiment supporting the existence of numerous, if far removed, life sites in the galaxy, "Show us one other example of life in the universe (i.e., on Mars) and up will go the tremendous dishes!" Prof. Morrison received the most enthusiastic and sustained applause of any speaker at the three SFRN panels.

• Relevant to the possibility of extraterrestrial life, Rainer Berger of Convair Scientific Research Laboratory has demonstrated that a beam of protons will produce urea, acetamide, and acetone in a mixture of methane, ammonia, and water at the temperature of liquid nitrogen. In Dr. Berger's opinion, his experiments support the possibility that precursors of life forms can be created throughout space. His report appears in the September Proceedings of the National Academy of Sciences.

BACKGROUND RUMBLE

• A consecutive study group known as the American Assembly, sponsored by Columbia Univ., has cautioned against a national obsession with the race to put a man on the moon and called for proper balance among programs in the national interest. It recommends more planning by government, business, universities, and independent research groups on the political, economic, and technological questions raised by the space race. ♦♦




Thiokol

For the record

The month's news in review

Sept. *6*—AF Titan hits on target in 6100-mi. flight.

Sept. *7*—Titan is successfully fired 5000 mi. in flight test of inertial-guidance system being developed for Titan II.

—NASA picks government-owned Michoud Ordnance Plant, near New Orleans, La., as site for fabrication and assembly of 1.5-million-lb-thrust Saturn C-1 booster.

Sept. *9*—Samos III blows up on launching pad.

—Nike-Zeus explodes 6 sec after launch.

Sept. *10*—Tiros III detects Hurricane Esther forming over mid-Atlantic, first hurricane to be discovered by a satellite.

Sept. *12*—Joe Walker pilots X-15 to 3645-mph speed record, despite cabin pressure failure.

—Discoverer XXX is fired into polar orbit

Sept. *13*—NASA orbits unmanned Mercury vehicle and returns it safely back to earth after one trip around our planet.

—Russian multistage rocket is successfully fired 7500 mi. into Pacific within about 1000 yd of its target in first of a series of test shots of "new, more powerful carrier rockets" for use in space exploration.

Sept. *14*—Ford Motor Co.'s Aeronutronic Div. unveils 100-lb ball-shaped lunar capsule—25 in. in diam and having a thick balsa wood outer shell—developed for the Ranger program.

—AF plane recovers Discoverer XXX capsule in mid-air.

Sept. *17*—Discoverer XXXI is orbited.

—Russians successfully test-fire multistage rocket 7500 mi. into Pacific.

Sept. *19*—NASA selects Houston, Tex., as site for its $60-million-dollar Space Flight Laboratory, command center for the nation's program to send manned expeditions to the moon and the planets.

Sept. *20*—D. Brainerd Holmes, former general manager, RCA's Major Defense Systems Div., is named director of NASA's newly created Office of Manned Space Flight Programs.

—AF says it has lost radio contact with Discoverer XXXI.

Sept. *21*—Soviet Union launches third in a series of rocket firings into the Pacific, but provides no details.

Sept. *23*—Titan is successfully raised from a 165-ft silo and fired 4500 mi. from Vandenberg AFB.

Sept. *25*—Republic Aviation plasma-pinch engine develops 100th of a pound of thrust in its first demonstration.

Sept. *28*—NASA announces it will use the Atlas-Agena B rocket instead of Centaur for the Venus probe, due to developmental difficulties with Centaur.

Sept. *30*—Air Force Systems Command announces consolidation of all AF bioastronautics research under the new Bioastronautics Div., Brooks AFB, San Antonio, Tex.

—AF Maj. Robert M. White and Joseph A. Walker of NASA, X-15 pilots, are awarded the Iven Kinchelow Award. ♦♦

Army Funds Nike-Zeus

In late September, the Army awarded Western Electric Co. a $171,821,000 contract to extend development and tests of the Nike-Zeus system for an additional 12 months.

Subcontractors and suppliers in many states will share in the contract's funding, including the Bell Telephone Laboratories, Whippany, N.J., responsible for system design and development, and the Douglas Aircraft Co., Santa Monica, Calif., builders of the missile.

Among other subcontractors funded under the contract are the Goodyear Aircraft Co., Akron, Ohio, Continental Electronics, Dallas, Tex., Avco-Everett Research Laboratories, Everett, Mass., Cornell Aeronautical Laboratories, Buffalo, N.Y., Continental Can Co., Coffeeville, Kan., Remington Rand Univac, St. Paul, Minn., Sperry Rand, Great Neck, L.I., and the New Mexico State Univ., Las Cruces, N.M. ARGMA supervises the development.

Some of the new funds will be expended for work at major Nike-Zeus test sites—at Ascension Island in the South Atlantic, White Sands Missile Range, and Pacific Missile Range Headquarters, Pt. Mugu, Calif. The fifth and largest site, a complete Nike-Zeus installation, is nearing completion on Kwajalein Island in the South Pacific. Next year, Nike-Zeus will be fired and controlled from Kwajalein in tests against target cones launched by Atlas boosters from Vandenberg AFB.

CREATIVE CONTROVERSY IN INERTIAL GUIDANCE

Behind the inertial package you see here is the instructive history of a creative controversy.

It's the history of how the ingenious rebuttals of some Litton Systems people won an engineering debate by overcoming certain obstacles that had been roadblocking progress in airborne inertial navigation.

The equipment shown is the stable-platform unit of a Litton LN-3 navaid system, first to furnish operational aircraft with inertial navigation information to an accuracy within 1.5 nautical miles for each hour of varied flight maneuvers.

The debate: It had been known that an inertial platform could be built around two two-degree-of-freedom gyros in place of the three one-degree-of-freedom gyros that were the standard concept. And that such a change would offer a number of important advantages including high gyro angular momentum in a compact platform, better servo response characteristics, and freedom from air-bubble problems achieved through the use of low-viscosity damping fluid.

Many inertial engineers felt strongly that the difficulties encountered in trying to manufacture two-degree-of-freedom gyros would more than offset the promised benefits. The difficulty regarded with the most superstitious awe was the problem of adjusting the center of gravity, center of buoyancy and total weight of the float containing the gyro to achieve neutral buoyancy at a specified temperature and zero torque about all three axes, within extremely narrow tolerances.

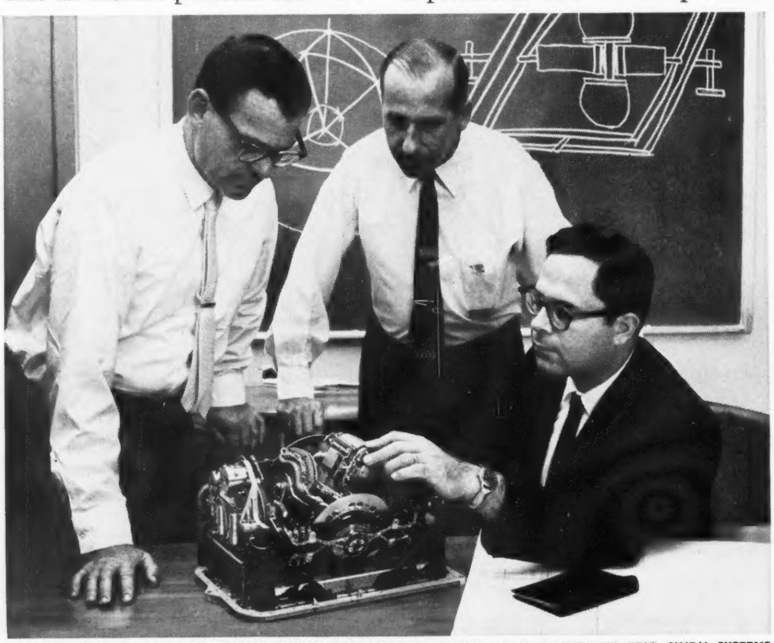
The additional restriction, that the weights placed on the float for balancing shall fall between a minimum and a maximum allowable size, increases the complexity of the actual balance procedure, placing it in the "linear programming" category from a computer standpoint.

The problem was solved by being programmed for solution on a digital computer in order to provide an efficient and reliable balancing process in production. The success of this approach is demonstrated by the world-wide operation of the Litton LN-3 aircraft navigation system, a proven lightweight system of high accuracy that uses two-degree-of-freedom gyros.

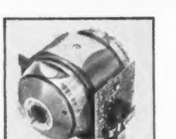
The same approach is being used to expedite the development of even more advanced systems, which will assure Litton's dominant position in the field. They include the Litton Doppler-Inertial System for the P3V anti-submarine patrol aircraft and the P-300 inertial platform of the Air Force Flight Data System for orbital and sub-orbital vehicles.

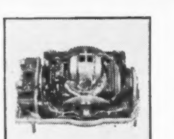
It's good to work in the atmosphere engendered when management fully appreciates the value of creative controversy that produces such results. Like-minded design and production engineers with applicable experience couldn't do better than to contact N. M. Pagan, Litton Systems, Inc., Guidance & Control Systems Division, 5500 Canoga Avenue, Woodland Hills, California.

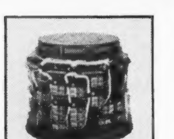
An equal opportunity employer



L-R: BRUCE SAWYER, HEAD OF ELECTROMECHANICAL ENGINEERING DEPARTMENT; GEORGE NORTHWAY, HEAD, GIMBAL SYSTEMS ENGINEERING; HAROLD ERDLEY, DIRECTOR OF ELECTROMECHANICAL PRODUCTS, GUIDANCE & CONTROL SYSTEMS DIVISION.





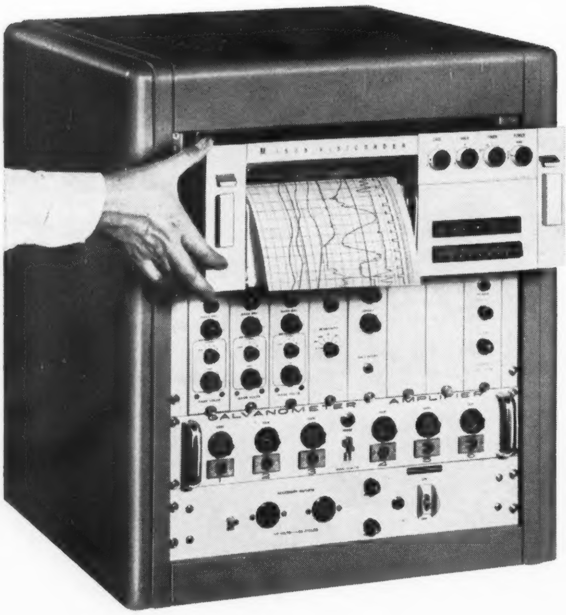


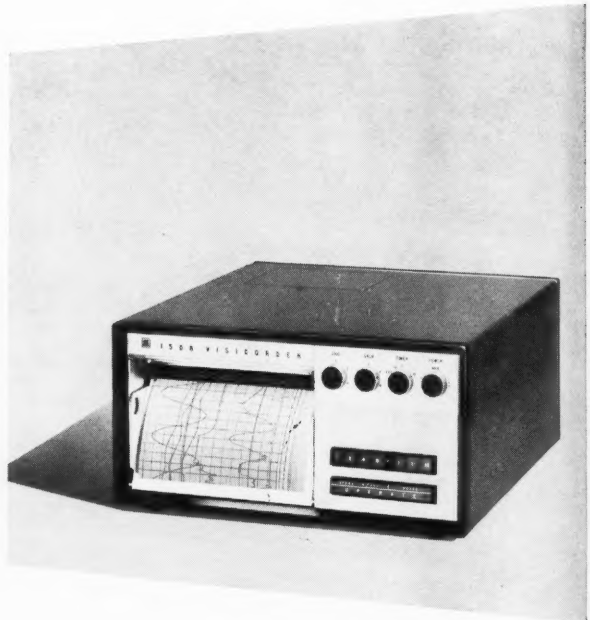
LITTON SYSTEMS, INC.

A DIVISION OF LITTON INDUSTRIES

GUIDANCE & CONTROL SYSTEMS • COMPUTER SYSTEMS • DATA HANDLING & DISPLAY SYSTEMS • SPACE SCIENCE • BIOELECTRONICS • ADVANCED COMMUNICATIONS TECHNOLOGY


The Making of History was not only His Privilege
... It was His Goal
If you are an advanced degree physicist, scientist or electronic management engineer who seeks to shape air and space vehicles to their unique environmental problems rather than stretch existing designs for marginal success, you are needed at McDonnell.
Write R. F. Kaletta, Professional Placement, McDonnell Aircraft, St. Louis 66, Missouri
AN EQUAL OPPORTUNITY EMPLOYER
UNITED
MCDONNELL
MCDONNELL





In your case, or in ours

The new 1508 Visicorder should be your next oscillograph

The Model 1508 Honeywell Visicorder has been specifically designed to quickly and easily slide into your data reduction system. There it will serve as a direct information read-out device, recording DC to 5000 cps on from one to 24 channels; or it may serve as a monitor on other components in your system; or it may do both jobs, simultaneously if you wish.

You have no "data reduction system," as such? Then consider the trim, convenient 1508 as a bench instrument. Its push-button controls, selection of 12 chart speeds (metric, if desired), 8″ paper width, and direct writing speeds exceeding 50,000 in./sec. will help to make it one of your most useful tools. Its rigid, cast base assures constant alignment of optical components regardless of external stress on the instrument.

In your case . . . the 1508 needs only 7″ of rack height. In ours . . . it arrives ready to go to work as a convenient, portable instrument. In *any* case, be sure to see the new 1508 Visicorder before you order your next oscillograph. Write for Catalog HC-1508 to Minneapolis-Honeywell, Heiland Division, 5200 East Evans, Denver 22, Colorado.

Honeywell

First in Control

Astronautics NOVEMBER 1961

An Open Letter

HUMANITY is on the threshold of one of its greatest adventures in all history—the exploration of space with manned vehicles. To be successful, this adventure will require the cooperative efforts of millions of people; and the benefits to humanity will match the magnitude of the effort.

Like all past endeavors to assuage our insatiable human curiosity, exploration of space will result in new materials, new technologies, and a better understanding of our environment. We will gain further knowledge of how to bend the laws of nature to the benefit of humanity. The urge to know and the ability to communicate knowledge have set humanity apart from the other forms of life on earth and have made us the dominant species here. The opportunity to extend our leadership into the rest of the universe is now at hand.

Just 31 years ago, a group of individuals dedicated to the exploration of space banned together to form what is now called the American Rocket Society. It was the purpose of the Society to cultivate interest in space exploration and to furnish media for the necessary effective communication of knowledge. These objectives have not changed. The American Rocket Society has now grown to over 20,000 members, the largest single group of its type in the world. Its communicative activities have expanded to the extent that it was able to sponsor last month the SPACE FLIGHT REPORT TO THE NATION, the most impressive series of exhibits and lectures on space ever staged.

Our nation's achievements in space are already impressive. We are led by our international competition in only one principal respect—that of high-thrust boosters for lifting heavy loads. These we know how to attain, and will eventually have. We lack these only because we did not start soon enough.

With the overwhelming scientific and engineering abilities of 20,000 ARS members, and with the productive plants of 168 ARS corporate members, the United States can be first in the space race. It is with justifiable pride that we offer you the greatest collection of skill and industrial capacity in all the world. This is the might that is needed for the task. It is yours to use in winning the race! And it is ready to go!

Harold W. Ritchey
PRESIDENT, AMERICAN ROCKET SOCIETY

Space guidance

Partial answers can now be given to some of the questions raised in the past few years concerning guidance, control, and navigation in coming lunar and interplanetary flights

By C. R. Gates, CHIEF OF SYSTEMS ANALYSIS
J. R. Scull, CHIEF OF SPACECRAFT CONTROL
K. S. Watkins, SENIOR PROJECT ENGINEER
NASA JET PROPULSION LABORATORY, PASADENA, CALIF.

SEVERAL years ago, as interest in unmanned lunar and planetary space exploration became more serious, a number of questions were often discussed, among them the following: (1) Can the boost vehicle be guided with sufficient accuracy so that no guidance is required after injection? (2) Is some form of midcourse guidance required, and, if so, should the midcourse-guidance system be located in the spacecraft or on the earth? (3) What new components are required for space guidance and to what extent can currently available components be utilized? (4) How does one accomplish a soft-landing on the lunar surface? (5) Is a space navigator, measuring the angles between observable bodies and located in the spacecraft, needed for interplanetary flight?

It is now possible to provide partial answers to some of these questions. For example, the launch vehicle, using guidance systems developed for ballistic missiles, cannot deliver a spacecraft to a space target with sufficient accuracy. Without guidance beyond the injection point, we would not be able reliably to hit the moon at all. And the miss at Mars or Venus would be several hundred thousand miles. However, a small midcourse maneuver, based on radio tracking data, executed a few hours or days after injection, and having a magnitude which requires only 1 or 2% of the spacecraft weight as rocket propellant, can easily reduce the miss at the moon to a few tens of miles and the miss at Mars or Venus to a few thousand miles.

For landing on the moon, a soft-landing guidance system, contained in the vehicle, can assume control of the spacecraft in the immediate vicinity of the moon.

For the interplanetary case, an approach-guidance system that commences its operation at a distance of 1- to 2-million miles from the planet and uses as inputs angles measured between the target planet and celestial bodies can reduce the error from a few thousand miles to a few tens or hundreds of miles.

Midcourse Guidance Performance*

Target	(1) Miss due to representative inject. guid., km	(2) Assumed track. accur.	(3) Orbit-determ. accur. from (2), km	(4) Midcourse man. to correct (1), m/sec	(5) Accur. of man. (assumed)		(6) Error due to man., km	(7) Tot. accur. (RMS of 3 and 6), km
					Point., deg	Mag., %		
Moon	6,000	2×10^{-3} rad, 0.15 m/sec	10	40	$\frac{1}{2}$	1	64	65
Mars	500,000	2×10^{-3} rad, 0.15 m/sec	2,500	20	$\frac{1}{2}$	1	5,400	6,000
Venus	300,000	2×10^{-3} rad, 0.15 m/sec	1,000	20	$\frac{1}{2}$	1	2,700	2,900

*All quantities are one-sigma.

Thus a midcourse-guidance system operating in the immediate vicinity of the earth, plus an approach- or terminal-guidance system operating in the immediate vicinity of the target, provides adequate guidance for deep-space missions, and a space navigator is not required.

Our discussion here will cover these guidance questions in greater detail.

EARTH-BASED MIDCOURSE GUIDANCE

By C. R. Gates

A practical axiom in space guidance is that any function which can be performed equally well on the earth or in the spacecraft should be performed on the earth. Since unmanned spacecraft must be tracked from the earth in order to receive information from them, tracking data are readily available. Also, most spacecraft will possess an attitude-sensing and -control system for pointing in any desired direction. Thus with the addition of a command link to the spacecraft and a propulsion system—the latter needed for guidance in any case—a guidance system is created. We wish to examine the capabilities of this guidance system.

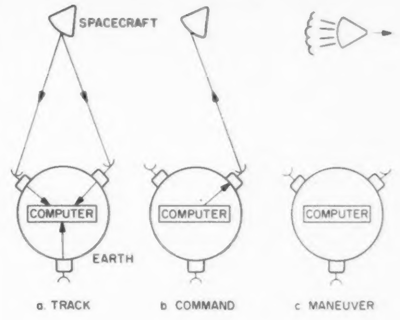
The drawing at top right shows the assumed guidance system schematically. Three tracking stations are assumed in order to provide continuous coverage. Tracking data are fed to a centrally located computer. Typical tracking data would be azimuth and elevation angles, range rate, and possibly range. The orbit is determined, and a command is transmitted to the spacecraft. The command consists of the direction and magnitude of the corrective-velocity maneuver required to adjust the trajectory. Then the spacecraft executes the maneuver.

The accuracy at the target, which may be Mars or possibly a given crater on the moon, will be affected by two almost independent error sources: Error in determining the orbit, based on tracking data, and error committed in the maneuver.

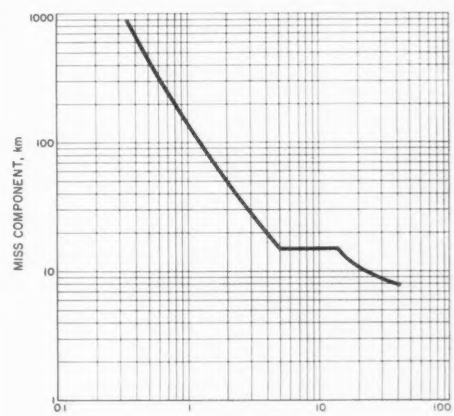
The accuracy of the orbit determination is affected by errors in the tracking data, in our knowledge of the locations of the tracking stations, in certain physical constants such as the velocity of propagation and the Astronomical Unit, and in computation. The mathematical procedure for orbit determination which has been found most effective for lunar and interplanetary flight is based on the maximum-likelihood method of statistical estimation, which, in effect, is a least-squares fit of the entire orbit. In this procedure, the fact that the spacecraft must obey Newton's laws, which are precisely known, is fully utilized.

The second graph at right shows an example of the accuracy of orbit determination for a lunar trajectory. Angular measurements accurate to approximately 2 mrad and range-rate measurements accurate to 0.15 meter per sec were assumed. The miss component, which is the semi-major axis of the 40% probability ellipse, may be interpreted as a sort of circular probable error. The horizontal portion of

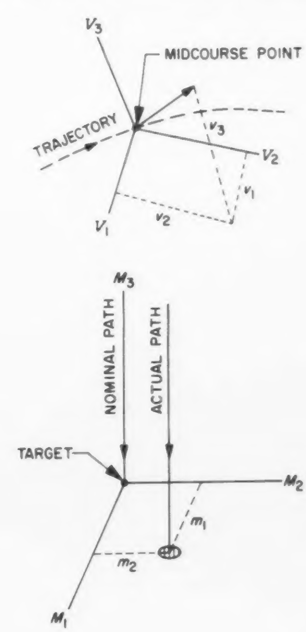
Guidance-System Operation



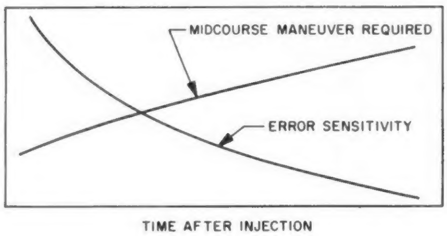
Lunar-Orbit-Determination Accuracy



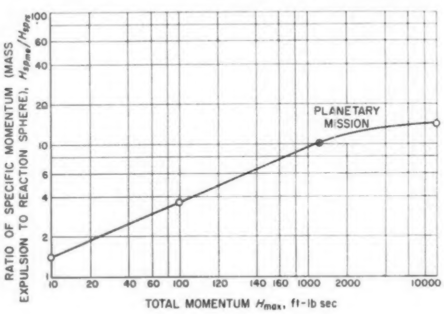
Midcourse-Maneuver Geometry



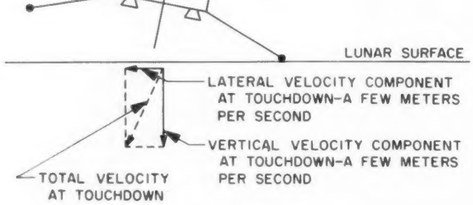
Midcourse-Maneuver Analysis



Comparison of Attitude-Control Methods



Assumed Lunar-Landing Conditions



the curve corresponds to a time at which it was assumed that the probe was not visible from a tracking station and, hence, no new data were being received. This graph shows that the first few hours of tracking data are especially powerful in determining the orbit. Also, as expected, the curve monotonically decreases downward, since additional data must always improve the accuracy, however slightly. Finally, we see that we can determine, with an accuracy of better than 10 km, where the spacecraft will impact on the moon. Corresponding accuracy for Mars and Venus would be approximately 1000 km.

If we could execute a midcourse maneuver perfectly, then the accuracy of this graph could be achieved. However, since errors will be made in the execution of a midcourse maneuver, and since we wish to minimize the magnitude of the maneuver while at the same time minimizing the miss distance at the target, some analysis of the maneuver will be necessary.

A midcourse maneuver is represented at the bottom of page 25. The maneuver ΔV is assumed to be executed instantaneously, and the orientation of the $V_1V_2V_3$ coordinate system is arbitrary. Below it, the target geometry is shown. The $M_1M_2M_3$ coordinate system is centered at the target and moves with it. The M_3 axis is taken as the direction of the standard or error-free trajectory. The actual trajectory is assumed to be parallel to the standard trajectory (a good assumption). The miss components m_1 and m_2 will be available from the orbit determination. The small shaded area indicates the uncertainty in m_1 and m_2. Let us next define sensitivity coefficients:

$$\lambda_{ij} = \frac{\partial m_i}{\partial v_j}$$

Since we wish to hit the target, we can then write

$$m_1' = -m_1 = \sum_{j=1}^{3} \lambda_{1j} v_j$$

$$m_2' = -m_2 = \sum_{j=1}^{3} \lambda_{2j} v_j$$

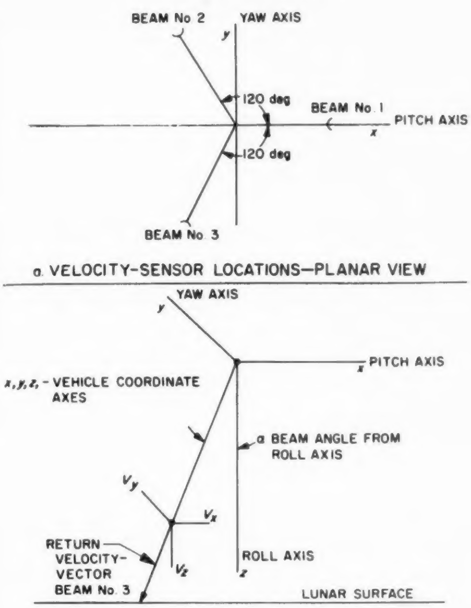
Observe, however, that we have two equations and three unknowns, the three unknowns being v_1, v_2, v_3. Thus one additional degree of freedom remains, resulting from the fact that the $M_1M_2M_3$ coordinate system moves with the target, and we have left free the time at which the spacecraft hits the target. The remaining degree of freedom could be used to control the time of flight or minimize the magnitude of the midcourse maneuver.

It now remains to determine the point at which the midcourse maneuver should be applied. The magnitude of the midcourse maneuver will be approximately proportional to the error at the injection point. However, for a given injection error, there are three conflicting criteria between which a compromise must be made:

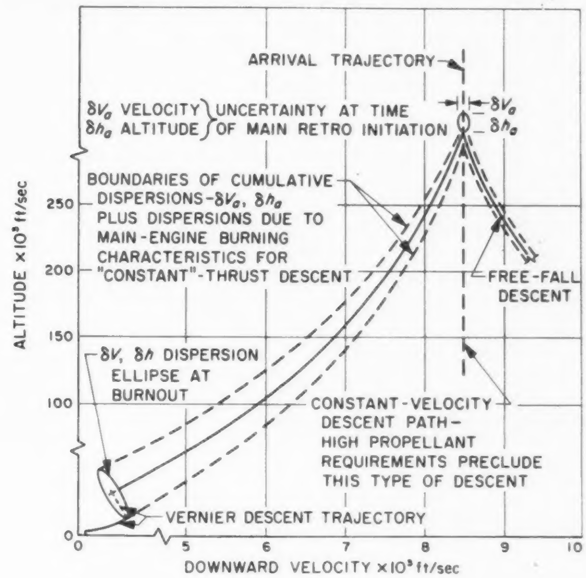
1. The accuracy of orbit determination improves as time increases, as shown by the graph on page 25, suggesting that the maneuver should be made as late as possible.

2. The magnitude of the required maneuver increases as

Velocity Sensing



Assumed First Burning-Phase Plane Descent Trajectory



time increases, as indicated by the graph on page 26, suggesting that the maneuver should be made as early as possible.

3. The sensitivity of errors at the target to errors committed during the midcourse maneuver decreases with time, as also indicated by the graph on page 26.

Fortunately, we find that the trade-off among these criteria yields broad optima, and the time of making the midcourse maneuver is not critical. For lunar trajectories, a time of 10 to 20 hr after injection is acceptable, and for interplanetary trajectories a time of from 1 to 3 days after injection is satisfactory.

Finally, certain key features of midcourse-guidance systems are summarized in the table on page 24. The figures in this table should be interpreted as being suggestive of the general region in which the quantities lie, rather than being precise.

SPACECRAFT GUIDANCE AND CONTROL SYSTEMS

By J. R. Scull

The spacecraft's own guidance control system must perform several functions. Orientation of part or all of the spacecraft toward the sun may be required for the generation of electrical power from panels of silicon solar cells as well as for thermal control of the spacecraft. In addition, because of the long communication distances involved in space flight, it is usually necessary to orient a directional antenna on the spacecraft toward the earth. Both of these requirements necessitate attitude measurement and control to only moderate accuracy (1 to 5 deg). Other orientation requirements may derive from scientific sensors, which may necessitate alignment toward the sun, a planet, etc. The most exacting accuracy requirements, however, come from guidance itself; we may desire to align the thrust vector of the spacecraft rocket motor to $^1/_4$ deg or better.

Inertial devices do not appear to be useful as a prime attitude reference for the long cruise portion of space flight for several reasons. First, the operating life of most rotating inertial components is not compatible with the flight duration of interplanetary spacecraft or operational satellites. Second, the errors of inertial components are a function of time; thus, unless reset by some external reference, the attitude accuracy of an inertial system is increasingly degraded from that occurring at injection or separation. Inertial devices do have a function in spacecraft for supplying rate, angle, or acceleration information for short periods of time during initial stabilization or acquisition and angular turns, for retaining attitude information when celestial sensors are obscured or are not within their field of view, and for autopilot reference during guidance maneuvers. Accelerometers are not useful for measuring gravity gradients much beyond a few hundred miles from the earth, but are required for determining the velocity increment of a midcourse or terminal maneuver. (CONTINUED ON PAGE 64)

Attitude control of spacecraft

Despite much literature, the state of the art has not changed radically in the past several years, and hardware proposals are receiving tough engineering scrutiny

By J. E. DeLisle, ASSISTANT DIRECTOR (SPACECRAFT GUIDANCE AND CONTROL)
B. M. Hildebrant, STAFF ENGINEER
I. D. Petranic, STAFF ENGINEER
MIT INSTRUMENTATION LABORATORY, CAMBRIDGE, MASS.

MOST of the literature on satellite and spacecraft attitude control may be divided into two types: Articles that deal with a particular actuating or sensing device, and articles that outline the entire subject while relying heavily upon an extensive reference list for completeness. The state of the art, as far as the unclassified literature is concerned, has not changed radically in the past few years. This fact, coupled with the great wealth of papers now appearing on the subject, makes the task of presenting a treatment from a fresh viewpoint difficult.

It was noted, however, that the amount of literature written on any particular method of attitude control is rarely in proportion to the relative worth of that method. This is natural because new methods are more properly the subject matter of technical papers than are conventional ones. There is, consequently, the possibility of overrating the potential of these innovations. It appears, then, that there is a need to establish a proper perspective on the subject and, in particular, to treat it from a practical viewpoint. Hence, this paper.

The fundamental law of attitude control is the rotational form of Newton's second law, which states that the time rate of change of angular momentum is equal to the vector sum of the applied torques. These applied torques will include all of the following, in varying degrees of magnitude: Earth's magnetic field, earth's electric field, sun's radiation pressure, pressure of electromagnetic radiation from the satellite, air drag, meteoroid bombardment, cosmic-ray bombardment, gravitational fields of celestial bodies, non-uniform rotation of reference coordinates, moving parts within the satellite, and the earth's gravitational field.[1]

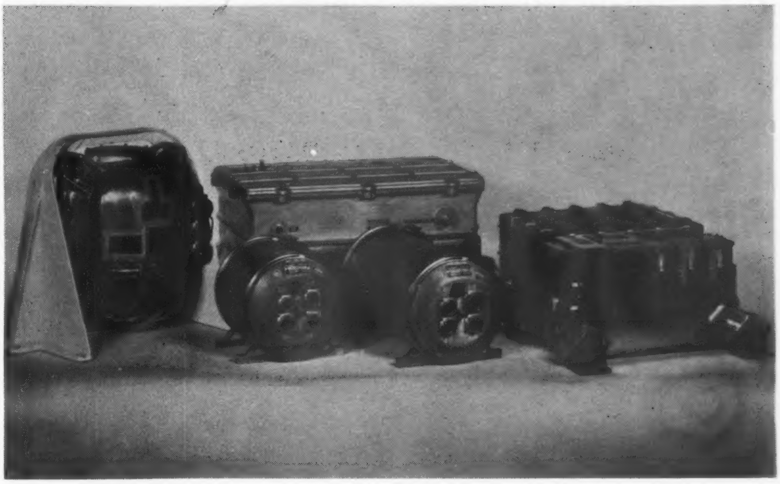
The attitude-sensing system has either or both of two functions: (1) To provide attitude information and (2) to provide signals to the control system proportional to the deviation or deviation rate of the vehicle from a desired attitude. The sensing methods discussed in the literature are numerous. Inertial methods include gyro-stabilized platforms, yaw gyros, and rate gyros. The principal methods using optics and radiation are celestial observation by telescope, center-of-illumination tracking, horizon scanning, celestial-rate sensing, and the velocity-over-height (V/H) technique.[2] Natural phenomena affecting the satellite's environment may also be used to advantage in sensor systems. Devices in this category include atmosphere, magnetic-field, gravity-gradient, and cosmic-ray sensors. Radio methods, which may be attractive in a few, restricted applications, form a fourth category.[3]

The primary methods of actuation are by the use of jet, inertial-reaction, and electromagnetic devices. Use may also be made of solar radiation, the gravity gradient, and aerodynamic effects.

First Satellite to Be Attitude-Controlled

Discoverer II, launched on April 13, 1959, was the first satellite to be attitude-controlled in orbit. It was stabilized, tail foremost, by an infrared horizon scanner and an inertial package.[4] Soon afterwards, a feat of much greater magnitude was claimed for the attitude-control system of Lunik III, the Russian vehicle which photographed the hidden side of the moon. Little information is available concerning the system, although it was reported to be comprised of optical, gyroscopic, and electronic computer apparatus and motors.[5] This equipment stopped all random motion, aligned the optical axis with the (CONTINUED ON PAGE 87)

The Centaur vehicle's inertial-guidance hardware includes, from left in the photo, a miniature inertial platform (four-gimbal, all-attitude, weight of 32 lb); pulse rebalance, gyro torquing, and power-supply package (total, about 50 lb); digital computer, associated input-output equipment, and control unit (total, about 57 lb); and, in the foreground, packaged cylindrically, a signal conditioner (10 lb) and platform electronics (18 lb).



Injection guidance

Existing programmed-attitude, radio, and inertial systems satisfy present and near-future space-vehicle requirements but reliability can be increased through better components

By R. J. Keeler and C. W. Benfield

AERONAUTICAL DIV., M-H REGULATOR CO., ST. PETERSBURG, FLA.

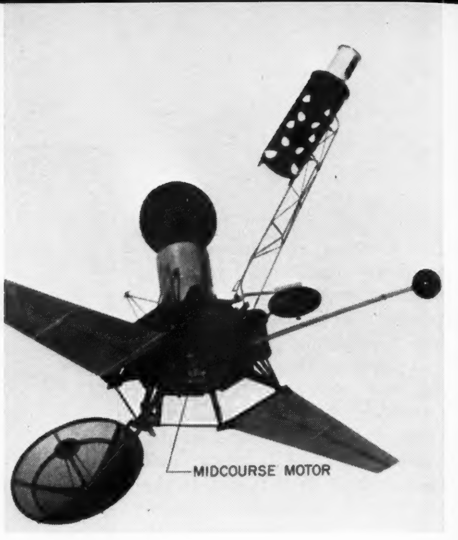
INJECTION guidance establishes the initial conditions for a spacecraft's orbit. How closely the subsequent ballistic motion coincides with that predicted by calculations depends upon several factors—adequacy of propulsion, accuracy of measurements, correctness of guidance equations (including knowledge of constants), precision of thrust control, and reliability of operation.

The basic geometry requires establishing a specified velocity magnitude, oriented in the required direction. This velocity may be visualized in terms of three orthogonal components, in the coordinate frame chosen. The position at cutoff can be visualized as three components in the same reference frame. Time of thrust cutoff is a seventh quantity which must be controlled to achieve a particular velocity condition on a more than transitory basis.

The simpler missions performed to date have allowed considerable freedom in some of these initial quantities. For example, the urgent needs of the U.S. space program in 1957 could have been met by "just any earth orbit." The only critical requirements for such an orbit are that velocity magnitude must equal or exceed circular velocity somewhere near cutoff altitude and that the vector velocity should be roughly horizontally oriented. The guidance systems which meet these requirements are relatively crude.

Changes of vehicle attitude in pitch, roll, and yaw are measured by integrating rate gyros which are fixed relative to the vehicle frame. A programmer-timer issues commands to the attitude-control system to cause programmed rotations through specified angles as a function of time. A single accelerometer with its sensitive axis aligned with the vehicle roll axis (the nominal thrust axis) permits fairly close determinations of accumulated velocity magnitude with one-time integration.

For guidance into orbit, the simple programmer commands a vertical booster firing for a pre-set time. A "pitch-over" maneuver then is commanded to bring the vehicle to an approximately horizontal attitude at an acceptably high altitude, and in a generally eastward direction. Thrust continues to accelerate the vehicle until the reaching of a predetermined cutoff velocity. (CONTINUED ON PAGE 90)



Simple guidance for deep-space booster vehicles

A relatively simple injection-guidance system used in conjunction with post-injection midcourse correction will be adequate for lunar and interplanetary missions

By Carl Pfeiffer

NASA JET PROPULSION LABORATORY, PASADENA, CALIF.

Carl G. Pfeiffer is supervisor of the Powered Flight Analysis Group of the Jet Propulsion Laboratory. After receiving a B.Me. degree from Cornell Univ. in 1954, he worked for Sperry Gyroscope Co. and then served two years in the U.S. Navy. He joined JPL in 1957, and since then has been engaged in guidance analysis of vehicle systems for NASA's deep-space missions. These analytical investigations have led to the development of techniques for specifying guidance requirements on the booster vehicles which will deliver lunar and interplanetary spacecraft from injection into orbit.

In planning lunar and interplanetary missions, we are up against a hard fact: The most advanced hardware does not yield sufficiently small injection-guidance errors to permit omitting a post-injection adjustment of the trajectory. This implies that midcourse-correction capability must be built into the spacecraft. It therefore may not be necessary to mechanize a very sophisticated pre-injection steering and shutoff guidance scheme. Instead, some simpler technique which yields injection errors of the same order of magnitude as the effect of component inaccuracy could be sought.

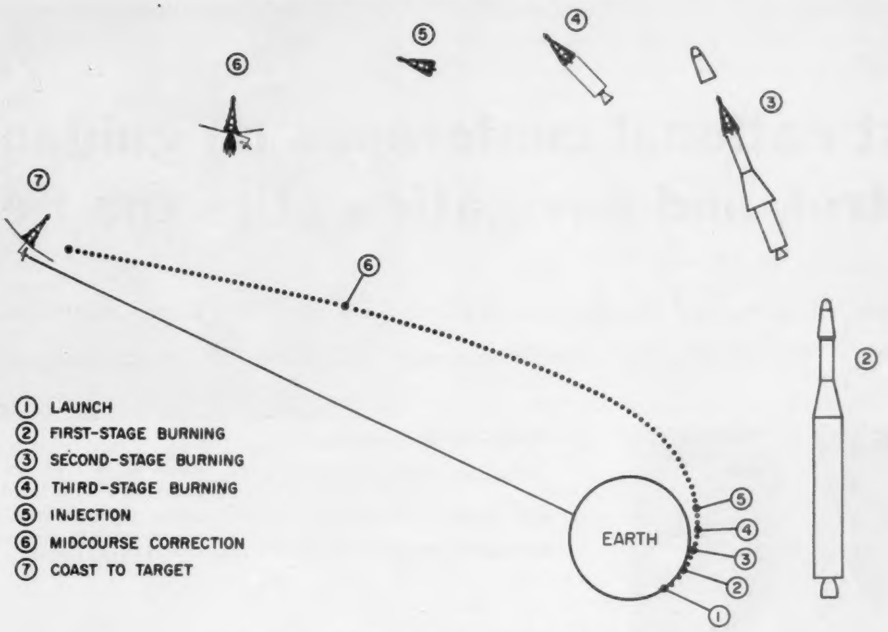
The question of just how rudimentary a guidance scheme can be is a problem which has to be examined in the light of an over-all system. Studies have indicated, however, that autopilot steering of the launch vehicle, with thrust termination of only the final stage on signal from a body-fixed accelerometer and integrator, might be entirely adequate. This conclusion has important implications for solid-propellant booster vehicles, where it might be inconvenient to mechanize a highly sophisticated guidance system.

Results of a JPL study are presented here to demonstrate the adequacy of a simple guidance scheme. It is shown that the use of a simple system requires additional midcourse propellant in an amount less than 1% of the spacecraft weight—a small penalty in terms of other gains through guidance simplicity.

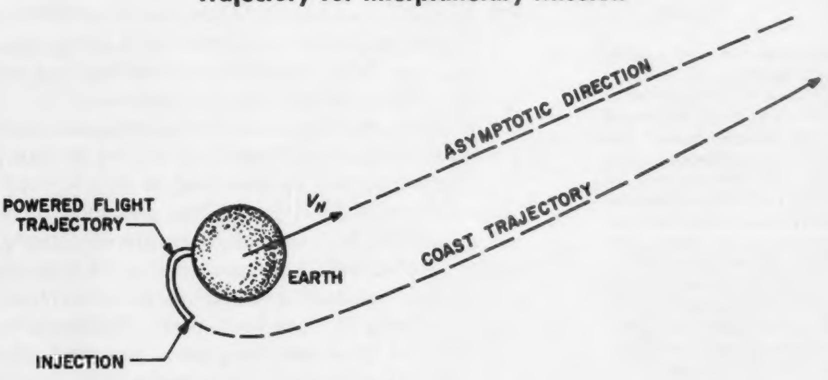
To begin with, we expect that guidance is necessary between launch and injection into a free-fall orbit to account for random variations in such powered-flight parameters as thrust level, propellant flow rate, aerodynamic forces, and liftoff weight.

The injection guidance problem consists of (1) determining the instantaneous position and velocity of the vehicle and (2), given these, computing steering and thrust-termination commands to achieve the desired end conditions. Part 1 of the problem is usually

Launch to Midcourse Sequence



Trajectory for Interplanetary Mission



Vehicle Configuration For Guidance Study

Complete vehicle weighing 8,867,000 lb launches 20,000-lb spacecraft payload.

Booster stage	Description	Gross weight, lb	Propellant weight, lb	Thrust level, lb	Isp, sec	Burning time, sec
1	Solid propellant	5,487,000	4,774,000	15,121,000	245	77.352
2	Solid propellant	2,167,000	1,907,000	9,960,000	271	51.887
3	Liquid propellant	1,193,000	1,074.000	1,400,000	420	322.203

accomplished by inertial sensors for injection guidance of deep-space vehicles, since the wide range of injection locations makes radio tracking impractical. Part 2 of the problem requires that a guidance scheme be devised, i.e., the formulation of guidance equations and the establishment of computational procedures for mechanizing these equations.

It is important at this point to distinguish between guidance and control. The guidance problem consists of determining the present and predicted position and velocity of the vehicle and of generating steering and motor-shutoff commands which will cause the vehicle to achieve satisfactory motor-burnout conditions. The control problem consists of determining how to mechanize accurately the steering commands, so as to get the response called for by the guidance system without causing vehicle instability. (CONTINUED ON PAGE 42)

First national conference on guidance, control, and navigation stirs the field

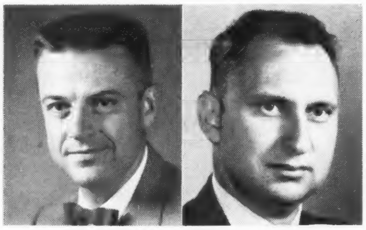
New plans, studies, and developments stir a field grown mature along certain lines . . . Relativistic experiments planned with very precise gyroscopes

By Robert H. Cannon Jr.

STANFORD UNIV., STANFORD, CALIF.

and James S. Farrior

LOCKHEED MISSILES AND SPACE CO., SUNNYVALE, CALIF.



Cannon **Farrior**

Program vice-chairman for the conference, Robert H. Cannon Jr. is an associate professor of aeronautical and electrical engineering at Stanford Univ. in charge of its programs on vehicle control and guidance. His early experience, from 1947–50, was on the development of hydrofoil boats, and in 1950 he delivered a thesis on hydrofoil-system behavior and received a doctorate from MIT. He then worked on missile guidance at the Bendix Research Laboratory in 1950–51, and was with Autonetics from 1951–57, involved in the development of autopilot systems and inertial-guidance components and systems. Dr. Cannon was an associate professor at MIT from 1957–59, before joining the Stanford faculty.

Chairman of the ARS Guidance and Control Committee, James S. Farrior is one of young old-timers in the guidance field. Now associate director of research for dynamics and navigation at Lockheed Missiles and Space Co., he recently headed the company's Guidance System Div. and, before that, the Guidance Dept., Polaris Missile System. From 1951–59, when he joined Lockheed, he held a number of positions with ABMA, the last as chief of its Navigation Branch, and was responsible for development there of guidance and control systems for the Redstone, Jupiter, and Pershing missiles and techniques used in the Jupiter-C and Saturn space projects. Farrior did his first work on inertial instruments for ballistic-missile guidance as an electrical engineer with GE's Guided Missile Center at Redstone Arsenal in 1950–51, shortly after receiving a degree from Alabama Polytechnic Institute.

An impressive proportion of the nation's guidance experts met August 7–9 at Stanford Univ. for the ARS-Sponsored National Conference on Guidance, Control, and Navigation—the first such meeting ever held. Need for the meeting was indicated by the turnout of over 800 scientists and engineers.

For old-timers in guidance and control, the conference was like a reunion, with a host of such pioneers as Helmut Schlitt, Walter Haeussermann, and T. Buchhold of the original V-2 team, C. Stark Draper of MIT, John Slater and John R. Moore of Autonetics, and W. R. Evans of Aeronutronic actively participating. Draper, Schlitt, and Moore presented major addresses.

First clue to national interest in the conference was the very strong response to a call for papers. Hardworking session chairmen selected 72 of the 185 papers submitted. Papers were divided into 15 sessions in three major areas: (1) An up-to-the-minute presentation of the state of the art of guidance components and systems; (2) an exposition of the role of guidance components and concepts in space operations; and (3) a preview of advanced concepts and advanced equipment which will be important in future guidance-system development.

Dr. Draper's keynote luncheon address focused attention on the vast improvements that have been made in recent years in the precision of measuring techniques and devices. Today's inertial instruments, he pointed out, perform to such a high degree of accuracy that it becomes extremely difficult to measure their performance with adequate precision.

In the second luncheon address, Dr. Schlitt, whose contributions go back to V-2 days, told of the difficulties facing early designers at a time when the poor performance of the limited types of available components made it necessary to resort to extremely simplified designs to obtain a reliable solution. He pointed out that, although the simple approach was dictated by the circumstances existing at that time, there is still much to be gained by applying the simplest designs which will provide acceptable performance.

The spinning manned space station presents one of the new challenges to the guidance and control field. Above, a model of such a station taken as a reference by Olstad and Grunberg of Grumman in their discussion of synthesis and mechanization of attitude controls.

A highlight of the conference was the banquet address by John R. Moore, president of Autonetics, who recapitulated of past accomplishments, and then stressed the tasks ahead—to develop guidance components and systems which are truly reliable, more producible, and more marketable. He pointed out the importance of seeking additional markets for guidance equipment, and cited undersea operations, "inner space," as having exciting potential.

In the closing luncheon address, L. I. Schiff, head of Stanford's Physics Dept. and noted relativity specialist, outlined an imaginative experiment to verify Einstein's general theory. This and other experiments were proposed at an inter-university and NASA conference held at Stanford in July. The first experimental demonstration would orbit a gyro of extreme precision—about 3×10^{-9} deg per hour—in a NASA Orbiting Astronomical Observatory. While the experiment would be of primary significance to theoretical physicists, Dr. Schiff pointed out that it could be accomplished only through a major guidance-engineering effort.

Three classified sessions, two chaired by A. D. Galbraith and one by J. S. Farrior, both of Lockheed, reviewed the state of the art of operational gyros and accelerometers—instruments which have been in existence for sufficient time to allow a good statistical evaluation of performance.

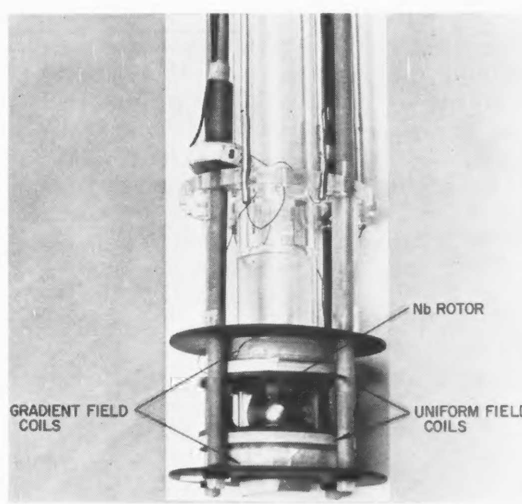
These sessions featured papers, in some cases presented by the inventors themselves, describing instruments which are pivotal in the nation's current scientific and weapons systems. Among the authors were such key contributors as Dr. Schlitt of Bell Aerosystems, L. R. Grohe of Nortronics, developer of several prime instruments at MIT's instrumentation laboratory, J. C. Boltinghous, who developed Autonetics' G-6 free-rotor gyro, and D. E. Wilcox, who developed the induction velocity meter at Autonetics.

Papers on the subject of gyroscopes were presented by C. O. Swanson of Kearfott, H. Schlitt of Bell Aerosystems, C. Karatzas of Ford Instrument, S. Osband of Arma, B. O'Connor of Bendix, L. F. Warnock of Lear, R. P. Durkee of Minneapolis-Honeywell, W. A. Ebert of Autonetics,, J. C. Boltinghous and S. W. Cogan of Autonetics, and L. R. Grohe of Nortronics.

Papers concerned with accelerometers were presented by D. E. Wilcox et al. of Autonetics; W. G. Wing of Sperry Gyroscope, C. Carden et al. of STL, M. Shabsis of Bell Aerosystems, and B. H. Evans et al. of STL.

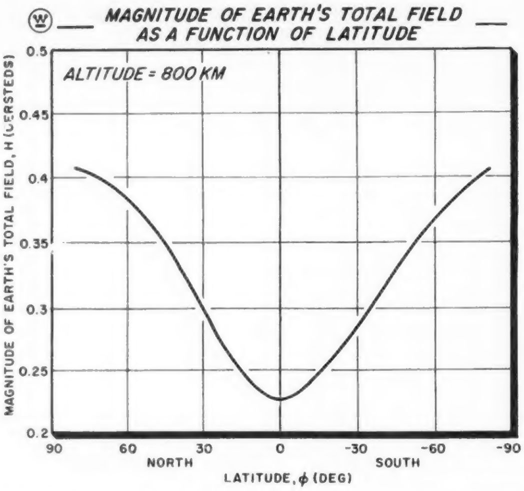
The design details, testing techniques, and performance discussed demonstrate the fact that today's inertial-systems designer has a good selection of high-quality inertial instruments. The need for more uniformity in gyroscope performance evaluation was stressed. Design and performance information presented was previously available only in company reports. Needless to say, every paper drew a capacity audience.

Highlight of a session on modern terrestrial navigation, chaired by J. A. Cestone of the Navy Special Projects Office, was the report by R. Kershner of Johns Hopkins Applied Physics Laboratory that recent results from the Transit program indicate



The magnetically suspended superconducting spherical gyro, shown above in a laboratory setup at NASA's Jet Propulsion Laboratory, contends for advanced guidance missions and might make possible relativity experiments in a satellite. J. T. Harding of JPL, T. A. Buchhold of GE-Schenectady, and W. M. Fairbank and M. Bol of Stanford Univ. discussed cryogenic gyro principles and developments and relativity experiments proposed to NASA.

The Earth's Magnetic Field—A Reaction Base for Satellite Attitude Control



A. G. Buckingham of Westinghouse Electric's Air Arms Div. presented a method for attitude control involving coupling with the earth's magnetic field.

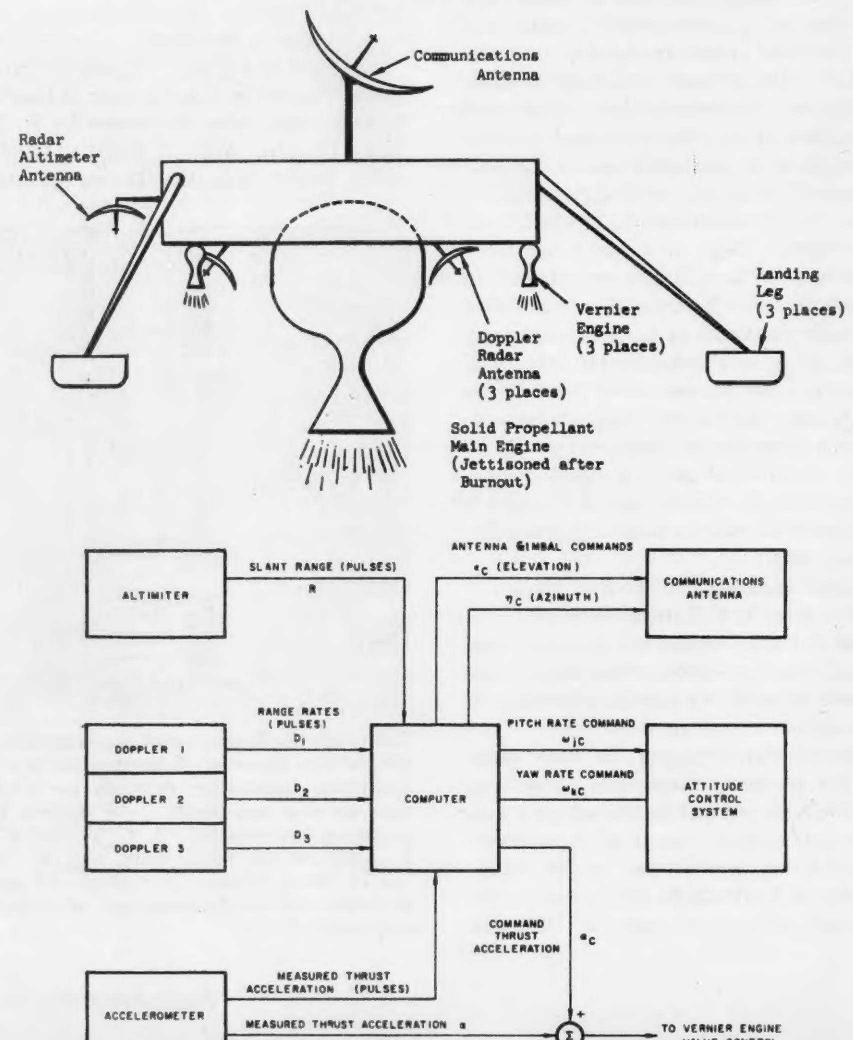
that the earth is an ellipsoid, not a spheroid. The major axis is in the equatorial plane and emerges at 11 deg west longitude. This redefinition of the earth's shape shows the Transit navigation system to be far more accurate than previous results indicated.

At the same session, techniques were described for improving the performance of purely inertial-navigation systems, including the use of several independent systems in parallel, the optimization of system damping, and application of the gyro-compassing technique to initial alignment.

R. R. Palmer of Autonetics showed how several independent inertial systems can be used in conjunction with platform rotation to reduce the error contributions of individual components and to re-bias all inertial instruments, except the azimuth gyro. The use of multiple systems can produce significantly improved (CONTINUED ON PAGE 45)

Lunar Terminal Guidance and Instrumentation Scheme

(Cheng and Pfeffer of STL)



Terrestrial guidance

The state of the art, advancing on a broad front in inertial optical, radio, satellite-referenced, and acoustical systems, makes possible wide choice of characteristics and performance

By J. M. Slater
AUTONETICS, A DIV. OF NORTH AMERICAN AVIATION, INC., DOWNEY, CALIF.

If the Ancient Mariner is disturbed when he sees a rocket-launched passenger capsule among his constellations, his equilibrium may be completely destroyed when he looks down to find a star-tracker window protruding from the water nearby. As a matter of fact, even to the sophisticated, the remarkable variety of vehicles moving in the ocean and in the sky, and of methods for guiding them, tend to obscure the fact that there are basic principles in common. Thus, broadly defined, navigation or guidance is the process of directing the movements of a craft, rocket, or other vehicle from one point to another. The process typically requires determination of *direction, speed,* and *distance* or position, in two or three dimensions, by measurements and computation. Methods differ mainly in the nature of the physical quantities measured. The things selected for measurement determine the nature of computation, any limitations on place and time of application, and the nature of errors.

In examining navigational methods, three considerations must be borne in mind. First, present-day accuracy requirements, for both military and civilian applications, are extremely high by any traditional standards. For example, in some oceanographic research, a continuous "fix" to 0.1 mi., anywhere and at any time, is desired. Second, continuity of output is required for autocontrol of vehicles. Third, reliability (another aspect of accuracy) has a significance which it never had before. A single missile, misnavigated, can result in loss of a war, or worse yet, in precipitating a war. Any complacency as regards the state of the guidance-instrumentation art, in respect to accuracy and reliability, would be hazardous.

Navigational methods can be classified in various ways. Our mode of classification will be as follows: (1) Methods based on measurements relative to an inertial (non-rotating) frame of reference—an earth-independent frame. This class is represented by inertial, celestial, and navigational-satellite systems. (2) Methods based on measurements relative to the terrestrial frame of reference. This class includes practically all other methods.

Methods and Applications

We will outline some of the principal navigational methods, indicate their status (within military security limitations), and suggest what course future developments may take. Although our two classes are of comparable importance, for brevity the present discussion will pay more attention to the first. That class, by reason of independence from natural or artificial earth-fixed sources of signals, is of special military importance, including submarine navigation and exploration in remote regions, e.g., the Arctic and Antarctic regions and the Indian Ocean. Moreover, it is the more pertinent of the two classes to extraterrestrial applications. In such projects as Apollo and Mercury, terrestrial and extraterrestrial navigation tend to merge.

Inertial Guidance. We shall begin with the so-called "inertial" method of guidance or navigation (which should have been called "Newtonian" inasmuch as the law of gravitation is of equal significance to its functioning as are the laws of motion). It is the only method applicable in theory at least to all terrestrial guidance problems, with the single but important exception of determining height or depth on a long-term basis. As a corollary, inertial sensing and measuring methods, constituting the only self-contained and continuously functioning means for determining kinematic quantities, will often be found at the core of systems which depend principally on non-inertial measurements. (An example is the precision gyroscopic attitude and heading reference required for Doppler-radar ground-speed systems.) The status of (CONTINUED ON PAGE 72)

Scientific sensors for space vehicles

Number, diversity, and new developments make keeping track of these instruments a problem

By James J. Leybourne, Associate Physicist

COMMUNICATIONS SYSTEMS CENTER

IBM FEDERAL SYSTEMS DIV., ROCKVILLE, MD.

Due to the increasing diversity of satellite and space-probe experiments, it is becoming more difficult for the engineer and scientist to keep abreast of new developments in sensors. The accompanying chart summarizes some of the characteristics of a number of instruments which have been used or are under development for making scientific measurements from a satellite or space probe. The data given in this chart are typical. Very exact values depend on the particular application of the instruments. For example, the counting rate of a Geiger-Mueller tube is not primarily a function of the type of tube (although this may establish an upper limit) but depends on the orbit of the satellite, the amount of shielding, and the circuitry used to record the pulses.

In this summary, the "Intrinsic Signal Form" is the type of output of the sensing element before processing, and does not depend on the circuitry. The "Range" and "Signal After Processing" and "Mode of Operation" are determined by the design of the experiment. These can be changed for different experiments by varying the circuitry, geometry, type of filters, etc. The column headed "Satellite and Space-Probe Environments" indicates the range of values expected for the scientific measurements, depending on whether the vehicle is in the vicinity of the earth or deep in space. ♦♦

Class of Experiments	Instruments	Intrinsic Signal Form	Range	Mode of Operation
Cosmic Rays	Geiger-Mueller Tube	D	10^5 cps	C
	Cerenkov Telescope	D-A	10^5 cps	C
	Cosmic Ray Telescope	D	5×10^3 cps	C
	Integrating Ionization Chamber	D	100 cps	C
	Nuclear Emulsion			C
Radiation Belts	Ionization Current Gage	A	10^{-11}–10^{-4}	C
	Thin-walled G-M Tube	D	10^5 cps	C
	Scintillation Counter	D-A	6×10^4 cps	C
Solar Particles	Electrostatic Analyzer	A	10^{-12}–10^{-4}	2 min
	Proton Ionization Gage	D	10^5 cps	C
	β-Ray Spectrometer	D-A	5×10^5 cps	C
	Ion Scintillation Spectrometer	D-A	5×10^5 cps	C
Magnetic Fields	Flux-gate Magnetometer	A	0.6–1200 γ	C
	Rotating-coil Magnetometer	A	0.6–1200 γ	C
	Proton-precession Magnetometer	F	0.07–1.0 G	10 sec
	Rubidium-vapor Magnetometer	F	0.05–105 γ	10 sec
Micrometeorites	Resistance Grids	A	12 levels	C
	Erosion Gage	A	2 decades	C
	Microphone	D-A	$>10^{-5}$ gm-cm/sec	C
	Light-flash Detector	D-A	$>10^{-3}$ erg	C
Spectroscopy	IR Spectrograph	A	2–4 μ	S
	UV Spectrograph	A	1750–3100 A°	S
	Lyman-alpha Telescope	A	1040–1340 A°	S
	X-Ray Telescope	D	2–8 A°	C
Ionosphere	Ion Probe	A	$>10^3$ ions/cm	2 sec
	Langmuir Probe	A	$>10^3$ electrons/cm^3	1 sec
	Electric-field Meter	A	0–10 V	C
Radiation Budget	Albedo Meter (Scanning)	A	2 decades	C
	Omnidirectional Radiometer	A	2 decades	C
	Neutron Proportional Counter	D	1000 cps	C
Atmospheric Pressure	Thermionic Ionization Gage	A	10^{-5}–10^{-9} mm Hg	C
	Radioactive Ionization Gage	A	1 atm–10^{-4} mm Hg	C
	Cold-cathode Ionization Gage	A	10^{-5}–10^{-7} mm Hg	C
	Redhead Gage	A	$>10^{-13}$ mm Hg	C
	Pirani Gage	A	10^{-1}–10^{-3} mm Hg	C
Atmospheric Structure	RF Mass Spectrometer	A	2 decades	1 se
	Magnetic Mass Spectrometer	A	10^{-6} amp	5 se
	Thermistors	A	3 decades	C
	Thermocouples	A	2 decades	C

Abbreviations: D = Digital A = Analog D-A = Discrete event with analog magnitude F = Frequency γ = Gamma G = Gauss C = Continuous

Mode of Operation	Signal After Processing (Pulse Height Analysis, Scaling, Amplification, etc.)	Satellite and Space-Probe Environments	Comments
C	Current measured or pulses counted.	Normal counting rates in space are low (about 10 cps) but may increase by a factor of 1000 during a solar flare.	Intensities in space are within G-M tube range.
C	Analyzed by pulse height and counted.		Measures particles with relativistic velocities.
C	Pulses scaled 2^5 and counted.		Uses a triple-coincidence circuit.
C	Pulses counted.	Normal rate expected is 1 pulse per hr.	Each pulse represents 1.8×10^{-4} roentgen.
C	Package recovered and tracks analyzed.	Exposure time will be several days.	Must be recovered.
C	Current measured.	Within the radiation belts, shielding must be used to prevent saturation of the counting circuits.	Measures total energy released in the detector.
C	Current measured or pulses counted.		10^5 cps is optimistic for a G-M tube.
C	Analyzed by pulse height and counted.		Limit of counting rate is set by the circuitry, not the crystal.
2 min	Current measured for each of 12 bias levels.	In space, counting rates are not expected to exceed 1000 cps; approximately 90% of the solar particles are protons.	Uses electrostatic focusing.
C	Pulses counted.		Uses "magnetic broom" to remove electrons.
C	Analyzed by pulse height and counted.		Uses magnetic focusing.
C	Sorted by particle type and analyzed by pulse height.		Thin crystal determines particle type, thick crystal measures energy.
C	Analog current proportional to component of field.	Field strength near earth is 0.7 gauss and slowly decreases to 2.5 gamma at approximately 13 earth radii; in space, surges of 40 gammas have been recorded.	Can be designed for almost any range.
C	A-M sinusoidal current proportional to component of field.		Measures component perpendicular to spin axis.
10 sec	Frequency proportional to magnitude of field.		Measures absolute field but can be used to measure components of field by using biasing coils.
10 sec	Frequency proportional to magnitude of field.		
C	Discrete changes in resistance.	Two hits were recorded in 1 sec.	Measures penetrating ability of larger particles.
C	Continuous slow increase in resistance.	Several months exposure are necessary.	Measures surface erosion due to sand blast effect.
C	Analyzed by pulse height and counted.	Rates of 5 cps have been recorded.	Records momentum.
C	Analyzed by pulse height and counted.		Measures light energy released upon impact.
S	About 20 peaks superimposed on 300-cps carrier.	Will scan surface of Mars.	Primarily interested in detecting lines characteristic of life.
S	About 80 peaks can be resolved.	Will scan surface of Venus.	For spectroscopic analysis of atmosphere.
S	Integrated current modulated by vehicle spin.	Produces pulse each time sun is scanned.	Lyman-alpha is strongest UV line from hydrogen.
C	Pulses counted.	Produces pulse each time sun is scanned.	Measures X-rays released during solar flares.
2 sec	2 analog currents versus time, 0.2-sec sweep.	Currents vary over two decades as probes pass through ionosphere.	Measures ion concentration and electron temperature.
1 sec	Analog current versus time.		Measures electron temperature and satellite potential.
C	Analog voltage on 1000-cps carrier.	Field strengths are about −5 vdc.	Measures field at surface of space vehicle.
C	Change in resistance due to scan.	Uses a reflector for scanning a limited field.	For studying energy balance in earth's atmosphere.
C	Change in resistance.	Uses a spherical surface to absorb radiation from all directions.	
C	Pulses counted for two detectors.	Expected rates are about 1000 cps.	Must be flown below Van Allen belts.
C	Ionization current collected varies over 3 decades; each detector must be laboratory-calibrated.	Range of pressures encountered are from 1 atm (at earth's surface) to as low as 10^{-14} mm Hg; the measured pressure depends on vehicle orientation and velocity.	Ionization caused by electrons from hot filament
C			Ionization caused by particles from radioactive emitter.
C			Ionization caused by electrons from cold cathode.
C			A specialized cold-cathode ionization gage.
C	Change in resistance (two decades).		Resistance of filament is decreased when cooled by gas.
1 sec	Analog current versus sweep voltage.	14 peaks have been resolved.	Satellite velocity vector must be taken into account when analyzing results.
5 sec	Current from many collectors commutated.	Measures preselected constituents.	
C	Logarithm of current.	Temperatures measured are space-craft temperature—not atmospheric temeprature.	Atmospheric temperature must be inferred from kinetic theory since radiation is chief mode of energy transfer.
C	Voltage change.		

The ARS-AFOSR International Hypersonics Conference

Three hundred and seventy-five hear timely theoretical studies and experimental results . . . The Russians give no papers

By Albert D. Wood and Adrian Pallone

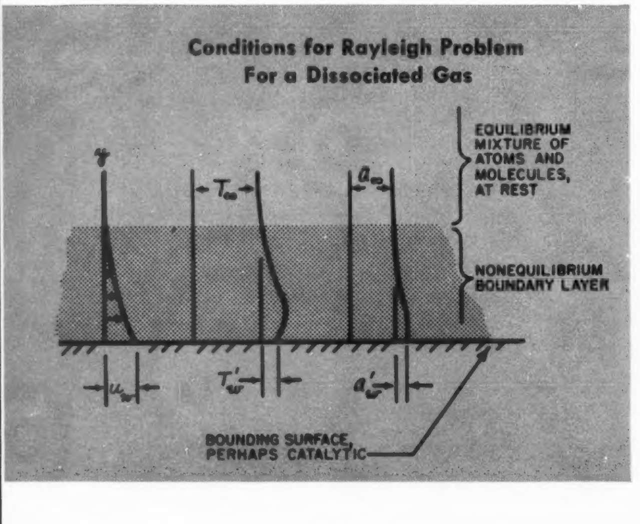
AVCO RESEARCH AND ADVANCED DEVELOPMENT DIV., WILMINGTON, MASS.

THE International Hypersonics Conference, held August 16–18 at the Massachusetts Institute of Technology under the co-sponsorship of the American Rocket Society and the Air Force Office of Scientific Research, drew a large and enthusiastic attendance.

The meeting was divided into five technical sessions at which a total of 23 papers were read, covering both theoretical and experimental aspects of hypersonic flows, including inviscid analyses and low Reynolds number and chemical kinetic effects.

The opening session was held on Wednesday morning and dealt with theoretical work on low Reynolds number hypersonic flows. Lester Lees served as chairman and contributed several interesting and pertinent observations.

In the first paper, by H. Oguchi, titled "Density Behavior Along the Stagnation Line of a Blunt Body in Hyperthermal Flow," an analytic solution, based on a Boltzmann representation of the gas, was found along the stagnation streamline. A plot of density variation along this streamline showed a decrease in density with increasing distance from the stagnation point, and gave no indication of any shock structure. This is, of course, not surprising since, as pointed out by Lees, the approach followed by Oguchi is valid only for very small Reynolds numbers, for which no shock would be expected. D. R. Willis mentioned that Oguchi's analysis was similar to the first iteration of a technique followed by himself for the problem of a piston being pushed into still air, where he had found that for Reynolds numbers at which a shock would be expected, the shock structure did not begin to appear until later iteraions involving higher-order approximations.



The second paper, "Second Order Boundary-Layer Theory for Blunt Bodies in Hypersonic Flow," by M. Van Dyke, was a very informative presentation which did much to clarify the present uncertainty with regard to the effect of external vorticity upon the boundary layer. In particular a systematic expansion scheme, which also contains the conventional boundary-layer results, is presented for the determination of viscous hypersonic continuum flow near the nose of a blunt body. Inasmuch as many of the other effects which are neglected in conventional boundary-layer flow are equally as important as vorticity, seven second-order effects are considered: Longitudinal and transverse curvature, slip and temperature jump, entropy and total enthalpy gradients, and displacement effects. Unfortunately, while it was shown to be feasible to calculate each of these effects, the only actual numerical results to be presented were for the combined influence of slip and temperature jump. This was shown to be of the order of 20% of the vorticity

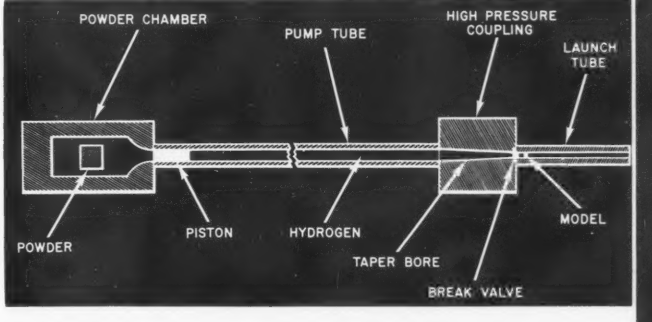
effect and of opposite sign, and hence certainly not negligible. It was further stated that the remaining second-order effects would also be of opposite sign to the vorticity effect, with the result that the total of all these effects would tend to be very small.

Other Opinions on the Subject

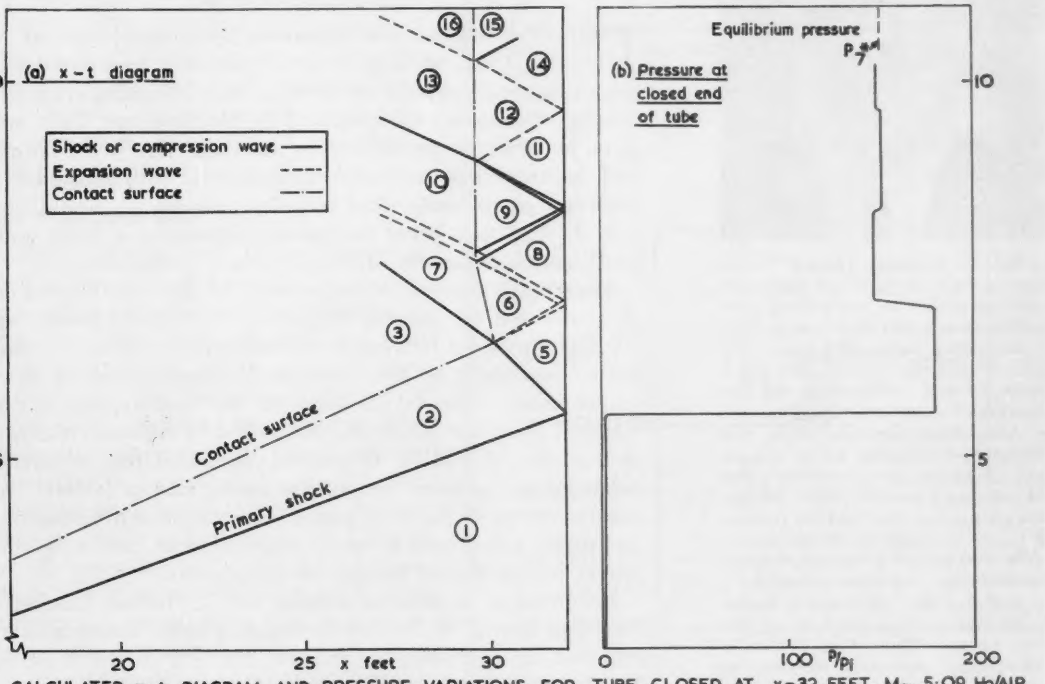
A rather lively discussion followed the presentation, and included a prepared comment by M. Lenard on similar work he has done on the problem. Lees cautioned that while such a systematic expansion procedure is formally correct and leads mathematically to just one answer, the analysis is not always relevant. In particular, as was mentioned by Lees and re-emphasized by R. Probstein, some significant factors involve non-linear effects which cannot be taken into account in such a procedure.

The third paper of the session, "Rarefield Hypersonic Flow Over a Sphere" by E. S. Levinsky and H. Yoshihara, presented a direct numerical integration technique for the Navier-Stokes equations appropriately simplified for the stagnation region. The simplification involves approximating the equations as a parabolic system, giving rise to a locally similar solution. Results, including flow-field profiles from the body to the free stream, were presented for both adiabatic and cold-wall cases over a range of Reynolds numbers extending from boundary-layer to merged layer regimes. A major part of the discussion following the paper involved a question raised by H. K. Cheng concerning the validity of a parabolic approximation of a system of equations which is basically elliptic in nature, with the resulting elimination of the known physical influence of the downstream flow on the solution in the stagnation region. M. Van Dyke mentioned that he had carried out an investigation of this effect for the inviscid flow (CONTINUED ON PAGE 82)

Accelerated Reservoir Light-Gas Gun



Typical Calculated Wave Pattern for Shock-Tunnel Operation



CALCULATED x-t DIAGRAM AND PRESSURE VARIATIONS FOR TUBE CLOSED AT x=32 FEET. M_{S1} 5·09, H_2/AIR

On the evening of the second day of the meeting, after a fine review paper given by George W. Sutton and co-authored by Per Gloersen, both of GE, the members of this panel paced each other through an exciting summary and evaluation of MHD power and propulsion developments. Participants, from left—the panel chairman, Allan Penfold of Litton Industries, Alfred Kuhnen of Republic Aviation, George Sutton of GE Space Sciences Lab, G. Sargent Janes of Avco-Everett, George Wood of NASA-Langley (standing), and Stewart Way of Westinghouse.

ARS-Northwestern MHD Symposium

A field in flux shows interesting experimental results . . . Brilliant panel sparks meeting

By Gerald R. Seemann

NORTHWESTERN UNIVERSITY, EVANSTON, ILL.

Gerald R. Seemann entered Northwestern Univ. in the fall of 1960 after receiving a B.S. in mechanical engineering from Texas Tech and an M.S. in mechanical engineering from Oklahoma State Univ. He is presently a senior doctoral candidate in the Gas Dynamics Laboratory, doing research in magnetoaerodynamic drag and magnetohydrodynamic power generation. Seemann was a teaching assistant and then a research fellow at Oklahoma State, and also held the position of senior engineer at Martin-Denver while working on a liquid-hydrogen–liquid-oxygen propulsion system for a lunar spacecraft. He is now a Walter P. Murphy Fellow, secretary of the Northwestern Univ. Gas Dynamics Colloquium, associate member of Sigma Xi, and a member of ARS.

THE Fourth Biennial Gas Dynamics Symposium, held at Northwestern Univ. on August 23–25, provided an informative and stimulating exchange among the more than 200 engineers and scientists in attendance. Co-sponsored by Northwestern Univ. and the ARS, as were the previous three meetings, this year's symposium took as its subject, magnetohydrodynamics, with 24 papers being presented at six unclassified technical sessions. A seventh session was devoted to a panel discussion followed by a lively audience participation period on MHD power and propulsion.

The Fourth Biennial was sponsored by the ARS Magnetohydrodynamics and the Electric Propulsion Technical Committees and the Gas Dynamics Laboratory of Northwestern Univ. It was supported financially by five government sponsors and 24 industrial corporations. The co-chairmen of the symposium—Ali Bulent Cambel, Thomas P. Anderson, and Milton M. Slawsky, who is chairman of the ARS MHD Committee—organized this conference by achieving an optimum compromise among various factors: A full-scale coverage of the field, ample presentation and discussion time per paper, a balanced program, single sessions, and a length consistent with sustained interest by participants.

Following a welcoming address by Ali Bulent Cambel, ARS President Harold W. Ritchey expressed a belief shared by all present—that in magnetohydrodynamics lies one of the most important research fronts open to mankind.

The opening paper by Paul S. Lykoudis of Purdue Univ. was an astute review of classical flows in MFM with a refreshing approach, obtaining first order results without employing complex mathematics. He did, in addition, however, introduce his own analysis of a blast-wave problem in MFM and a brief discussion of wall turbulence.

Meredith C. Gourdine of Plasmadyne Corp. considered an incompressible, viscous, electrically conducting fluid flowing steadily in a long cylindrical channel in the presence of a parallel magnetic field, subjected to the torque produced by a radial current sheet interacting with the magnetic field. This torque causes rotation of the fluid upstream and downstream due to viscosity. It was found that for the Alfven number greater than unity, the disturbance propagates both upstream and downstream to infinity ($AL = V_a/V$).

Ziering and Kahalas of Allied Research Associates, Inc., reviewed the moment methods upon which many investigations in transport theory depend. Standard problems in kinetic theory ranging from free-molecule to continuum flow were examined with respect to the validity of the various moment methods. It was shown that the discontinuous nature of the distribution function at a boundary must be explicitly recognized and incorporated into the kinetic theory.

Peng and Pindroh of Boeing made a higher-order approximation of both thermodynamic and transport properties of gases or arbitrary gas mixtures. The calculations were based on a nine-specie (N_2, O_2, NO, N, O, N^+, O^+, NO^+, e^-) gas. The transport properties are considered to be within 5% of the most exact theoretical predictions. The calculations were made within the range of temperature 500 to 1500 K and density 10^{-5} to 10 amagats.

New Hot Hydrogen Data

B. Wahl, J. McKee, and Robert Gould of Douglas Aircraft reviewed theoretical efforts concerning radiative properties of hot hydrogen at high pressures. This work was extended, and applied to calculate the radiation from a nonuniform gas body. The absorption coefficient for hydrogen at these conditions was found to differ appreciably from the results of calculations by Unsöld and other investigators.

The banquet held in the evening of the first day had as its Master of Ceremonies G. Edward Pendray, who most ably performed the toastmaster duties. The guest speaker Dean I. W. Cole of Northwestern's Medill School of Journalism gave the scientist-dominated audience a look at the other side of the coin as he spoke on "Science and the Press." Dean (CONTINUED ON PAGE 53)

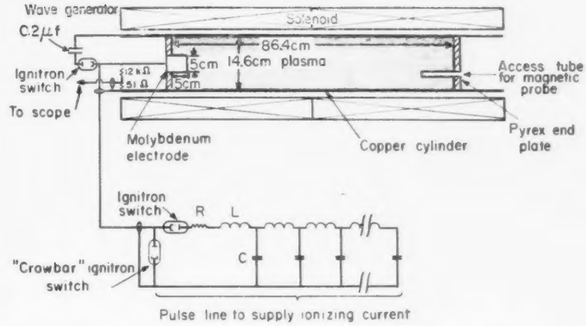
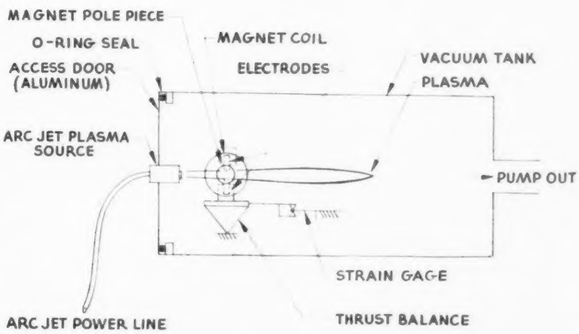
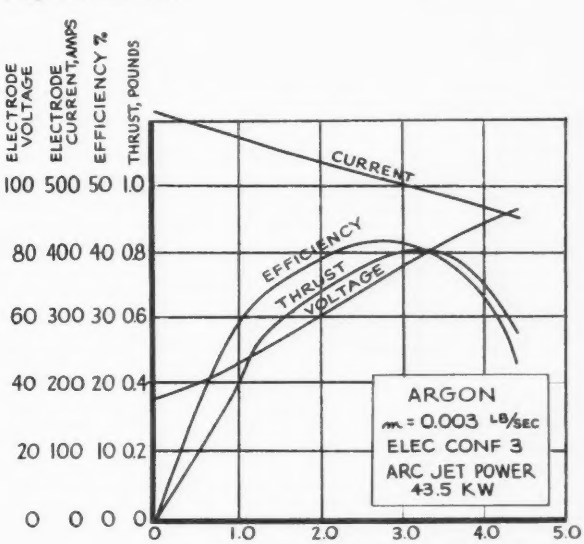


Diagram of experimental apparatus used by DeSilva et al. of UC Lawrence Radiation Laboratory to study Alfven-wave propagation.



Above, diagram of experimental MHD apparatus and, below, its experimental performance with argon plasma, from the work of Demetriades and Ziemer of Northrop Corp.'s Norair Div.



Simple Guidance

(CONTINUED FROM PAGE 31)

Although it is possible to separate the control and guidance problems for an analysis, these functions are often inseparable when it comes to designing equipment for the vehicle. The control problem will not be discussed further; but it can be assumed that the control-system configuration implied by the guidance analysis presented here will be consistent with the state of the art for solid and liquid boosters.

It is appropriate to look for some injection criterion which allows a relatively simple mathematical description of the desired injection conditions for deep-space missions. Such a simple formulation is available in the "energy-asymptote" principle. This concept has been discussed elsewhere.[1-3] Suffice it to say here that the task of the pre-injection guidance system is to inject the spacecraft into a coast orbit near the earth in such a way as to cause it to be traveling in the right direction (along the "asymptote") and at the right speed (equal to the square root of twice the specific energy of the vehicle) as it escapes the earth. This is illustrated in the sketches on page 31. A similar formulation can be made for lunar missions, but a "pseudo-asymptote" must be defined since the spacecraft does not escape.

An analysis of the actual mechanization of any injection-guidance system inevitably shows that there will be some error in the injection conditions. Two basic error sources are involved:

1. Approximation error, which arises from a failure to mechanize the exact mathematical formulation of the guidance equations.
2. Component error, which arises from inaccuracies in the equipment used to measure vehicle position and velocity.

Injection-guidance systems usually employ inertial elements, since the wide range of injection locations and long burning arcs over the earth's surface preclude the possibility of adequately tracking the vehicle by radar before injection. Reasonable estimates of component error for inertial systems of the near future indicate that the injection errors will be sufficiently large to require that a midcourse correction of the orbit be made in order to accomplish the mission.[4] This is done by applying one or more relatively small corrective velocity impulses to the spacecraft sometime between injection and approach to the target. The data necessary to determine the post-injection trajectory would be obtained from radio and/or celestial devices. A sufficient time after injection must be allowed to attain radar visibility and gather the tracking data, which might cause the first maneuver to be made approximately one day after injection for interplanetary missions and approximately 15 hr after injection for lunar missions.

Characteristics of Standard Trajectory

Injection conditions:
- Arc turned from launch point = 20.615 deg
- Speed = 12,005.8 m/sec
- Altitude = 242.659 km
- Path angle = 15.973 deg above local horizontal

Escape (asymptotic) conditions:
- Escape speed = 4,863.5 m/sec
- Angle of escape velocity vector from launcher = 125.41 deg

Injection-Accuracy Requirements

If these contentions are accepted, it can be seen that the ultimate target accuracy depends upon the accuracy of applying the midcourse maneuver, and it might make sense to build a relatively simple injection-guidance system. This observation is the motivation for this paper. It does not follow that injection-accuracy requirements can be relaxed to a point where there is no injection guidance system at all. It is desirable that the magnitude of the midcourse maneuver be small because:

1. If only one midcourse maneuver is performed, there exist errors at the target proportional to the magnitude of this maneuver.
2. The amount of propellant required increases with the size of the midcourse maneuver, thereby reducing the payload weight of the spacecraft.

Target errors proportional to the magnitude of the maneuver arise from the fact that there are pointing and shutoff inaccuracies in the midcourse system just as in the injection system. The effect of these errors can be eliminated if several maneuvers are made, each correcting the previous one. For reliability reasons, however, it is best to plan for as few maneuvers as possible.

The propellant-weight problem is fairly obvious. Based on a statistical analysis of injection-guidance accuracy, a portion of spacecraft weight must be set aside for enough propellant to correct injection errors some reasonable percentage of the time. This, of course, detracts from payload capability. The propulsion weight required depends on where in the orbit it is planned to make the midcourse maneuver. The optimum point depends on the characteristics of the injection-guidance system errors. (Errors in injection speed should be corrected "early"; errors in direction of the injection velocity vector should be corrected "late.") Some loss in efficiency occurs if the optimum point is earlier than the time it takes to determine the orbit; but since the propulsion requirement is usually only a small percentage of the spacecraft weight, this is not a serious limitation.

Effect of Performance Variations on Midcourse Fuel Requirements

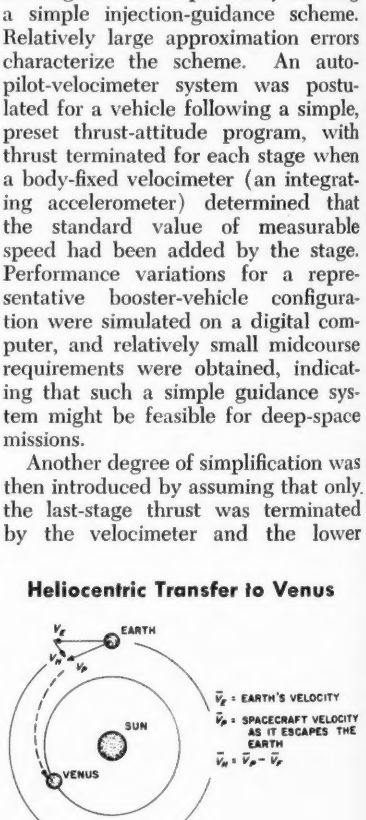
Root-mean-square maneuver = 21.4 m/sec

No.	Error Source	Std. dev., %	Required correction, m/sec
	Total Impulse		
1.	First stage	0.5	5.4
2.	Second stage	0.5	4.5
3.	Third stage	0.5	5.7
	Effective Burning Time		
4.	First stage	1.0	10.5
5.	Second stage	1.0	3.2
6.	Third stage	1.0	15.9

Such observations on the role of the midcourse maneuver led to an investigation of the possibility of using a simple injection-guidance scheme. Relatively large approximation errors characterize the scheme. An autopilot-velocimeter system was postulated for a vehicle following a simple, preset thrust-attitude program, with thrust terminated for each stage when a body-fixed velocimeter (an integrating accelerometer) determined that the standard value of measurable speed had been added by the stage. Performance variations for a representative booster-vehicle configuration were simulated on a digital computer, and relatively small midcourse requirements were obtained, indicating that such a simple guidance system might be feasible for deep-space missions.

Another degree of simplification was then introduced by assuming that only the last-stage thrust was terminated by the velocimeter and the lower

Heliocentric Transfer to Venus



Greater Mobility and Reliability for Today's Weapon Systems

Typical AiResearch gas turbine generator set

AiResearch gas turbine generator sets are now providing precise electrical power for mobile weapon systems in compact packages less than half the size and weight of previous systems.

These simplified power packages have fewer parts and provide dependable, quick starting and continuous trouble-free operation in any weather extreme.

Starting, loading and shutdown are completely automatic, push-button operations. And each package has scientifically-designed sound attenuation to minimize noise.

AiResearch is a leader in the design and production of small gas turbine engines and power conversion equipment. Please direct your inquiries to the AiResearch Phoenix Division.

GARRETT

AIRESEARCH MANUFACTURING DIVISIONS • *Los Angeles 45, California • Phoenix, Arizona*

Systems and Components for:
Aircraft, Missile, Spacecraft, Electronic, Nuclear and Industrial Applications

stages were burned to fuel depletion. This scheme has the advantage of not requiring a thrust-termination subsystem for the first two stages (important for solid boosters), and it produces a payload increase over the configuration that terminates all stages.

The payload saving follows from an analysis of propellant margin, which is the amount of additional propellant which must be carried in each stage to allow for late burning to correct for vehicle underperformance. Guidance terminating only the last stage allows the propellant margins to be combined as root-means-square instead of algebraically.

To study the autopilot-velocimeter guidance scheme, the vehicle configuration described in the table on page 31 was assumed, and a pre-injection trajectory adequate for a Mars or Venus mission was simulated on a digital computer. This was not a performance study, and the configuration described does not represent the optimum. It is, however, considered to be a feasible boost vehicle, and is illustrative of such a three-stage configuration.

Error Source

The thrust-attitude program was a simple one, causing the vehicle to rise almost vertically for 5 sec, pitch over at −1.012 deg per sec for the duration of the first stage, and then maintain a constant attitude of 11.772 deg above the launch horizon for the remaining two stages. A 10-sec coast was assumed between stages. Thrust termination was achieved by allowing the first two stages to burn to propellant depletion, the last stage being shut off when the correct value of launch-to-injection measured speed was computed with a body-fixed integrating accelerometer. The table on page 42 outlines the standard trajectory. The free-fall orbit attained is adequate for accomplishing a Venus or Mars mission.

To study the effect of approximation errors, it was assumed that there were random, uncorrelated, normally distributed variations in total thrust impulse and effective burning time in each stage with standard deviations of 0.5 and 1.0%, respectively. The magnitude of the midcourse maneuver to correct for each of these six independent error sources was computed by determining how each error source affected injection deviations and how these, in turn, caused the outgoing asymptote to vary. It was then assumed that the midcourse maneuver would be applied on the asymptote (long enough after injection so that the earth's gravitational field is negligible) to attain the standard escape conditions. This is actually a conservative assumption, since it would probably be more efficient to make the maneuver earlier. For this study, however, it is probably best to use this approach, since it is surely an upper bound.

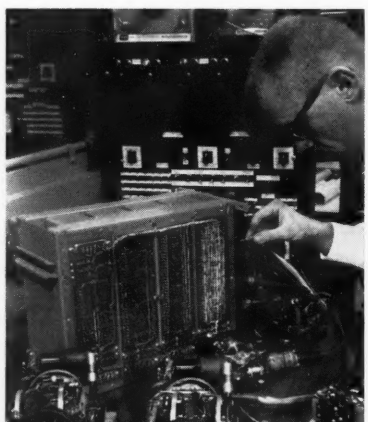
The table on page 42 gives the results of this analysis. The square root of the sum of the squares of the maneuver required for each error source is the standard deviation of the maneuver. A 99% probability of accomplishing the maneuver would be assured if about 2.5 times the standard deviation defines the propellant allotment. From the table just cited, it can be seen that 55 m/sec of maneuver would be an adequate allotment for approximation errors. If the specific impulse of the midcourse motor is 300 sec, then 30 m/sec corresponds to about 1% of the spacecraft weight. Thus, 55 m/sec requires less than 2% of spacecraft weight.

The midcourse maneuver must also correct for component errors, i.e., inaccuracies in the inertial elements that comprise the injection-guidance system. Some representative data on injection-guidance accuracy for an advanced inertial system have been given by H. J. Gordon of JPL.[4] When translated into required midcourse maneuver, these numbers yield approximately the same magnitude of maneuver as for the errors just discussed.

Assuming this to be so, it can be seen that using the simple system described in this paper rather than a more sophisticated scheme would at most cause an increase in midcourse requirements by a factor of $\sqrt{2}$. If 2% of the spacecraft weight was originally allotted to correct component error of a sophisticated system which had no approximation error, the cost of utilizing the simple scheme would be 0.828% of the payload weight. This might be a very reasonable price to pay when weight, reliability, cost, development time, and feasibility of a sophisticated system are considered.

Our discussion so far has been directed primarily toward the analysis of guidance of deep-space-mission booster vehicles. Satellite missions should be mentioned also. The conclusion that the midcourse maneuver can relatively easily correct for approximation error arising from a simple guidance scheme obviously does not hold if there is to be no such maneuver, as is normally the case for a satellite mission. If a correction to the satellite orbit were to be allowed, however, the adequacy of a simple guidance scheme might again be apparent. The orbit adjustment could be accomplished by tracking the orbiting vehicle over several revolutions and then performing the maneuver near perigee. It is important that the vehicle not re-enter the atmosphere before the adjustment can be made, so the nominal injection point must be chosen to allow the orbit to be maintained for a "three sigma low" energy variation. This causes the minimum attainable circular satellite orbit to be somewhat higher for a simple guidance scheme than for a more sophisticated system, but this is probably not a serious limitation.

Machine as Astronaut



Minneapolis-Honeywell engineer Duane Whaley looks over the Project Mercury automatic pilot, which consists of the five gyroscopes and the accelerometer in the foreground and the computer he is touching. Unless the astronaut elects to assume control for a time in orbit, this equipment "flys" the Mercury capsule after booster separation.

References

1. Sauer, C. G., Jr., *Interplanetary Injection Guidance*, Technical Report No. 34-88, Jet Propulsion Laboratory, Pasadena, California, October 25, 1960.
2. Moeckel, W. E., *Departure Trajectories for Interplanetary Vehicles*, TN-D-80, National Aeronautics and Space Administration, Washington, D.C., November 1959.
3. Pfeiffer, C. G., *Rudimentary Launch Guidance Methods for Deep-Space Missions*, Technical Report No. 34-43, Jet Propulsion Laboratory, Pasadena, California, April 30, 1960.
4. Gordon, H. J., *A Study of Injection Guidance Accuracy as Applied to Lunar and Interplanetary Missions*, Technical Report No. 32-90, Jet Propulsion Laboratory, Pasadena, California, May 1961.

First National Conference

(CONTINUED FROM PAGE 34)

accuracy as well as greater reliability through redundancy.

Two papers—one by C. Broxmeyer of MIT and another by A. L. Friedman of Dynamics Research Corp.—described how external information, such as vehicle velocity and position, can be used in the optimum way to improve the performance of a particular inertial system by damping the Schuler loop. It was shown, for example, that the use of position fixes is analogous to the use of sampled vehicle velocity. Both authors used the analogy with conventional aeromechanisms to apply advanced servo techniques.

The technique of aligning inertial-guidance systems in the field by gyrocompassing is now standard. The system's own instruments are used to sense the local vertical and direction of the earth's spin vector. The basic system dynamics, and the ultimate accuracy possible—using real instruments on a moving vehicle—were described in a paper by R. H. Cannon of Stanford Univ.

G. A. Harter of STL chaired a classified session on inertial guidance for ballistic missiles and space probes in which D. Plevin and W. Zdan of Arma described advanced concepts for mobile ground-launched and air-launched ballistic missiles. In addition, D. Meronek and R. Braslau of STL told of an advanced guidance system which uses Doppler velocity measurement to correct errors and thus improve pure-inertial-system performance. E. Metzger of Bell Aerosystems presented technical descriptions of the Hipernas guidance equipment. The Delta-minimum guidance techniques used on the Redstone, Jupiter, and Pershing missiles were discussed by J. Huff and W. Gudaitis of ABMA. S. Greif of Nortronics presented a paper on air-launched ballistic-missile guidance. An unclassified paper by H. J. Gordon of JPL discussed studies which JPL had made to determine the accuracy of a typical inertial-guidance system as applied to future lunar and interplanetary missions. The study indicates that it is of special importance to have one high-quality accelerometer and one high-quality gyro; improving other components would have a much smaller effect.

New Azimuth Alignment

One significant point brought out during the session was the capability for establishing azimuth alignment of an inertial-guidance system for a boost vehicle after launch. Recent developments make it possible for a system designer to include a star-position indicator on his platform for this important measurement. Another point discussed was availability of very stable oscillators of sufficient accuracy to facilitate use of a one-way Doppler system as an aid in improving inertial-system accuracy for launch guidance.

C. J. Mundo of Raytheon presided over two sessions, one entitled "Optical Techniques for Guidance" and the other "Optical Doppler and Radio Systems for Space Navigation." In a paper by C. R. Woods and E. B. Mullen of General Electric, it was stated that long-baseline, microwave, continuous-wave radar systems can be expected to give three-dimensional accuracies of from 1 to 10 ppm. Rates can be determined accurately by numerical differentiation of the position data, which is supplied at a high data rate. A practical problem arises in implementing accurate time signals over long baselines. Atomic clocks at present are only marginally useful for such purposes. J. W. Crooks Jr. et al. of General Dynamics/Astronautics discussed how sideband folding techniques might be applied to increase the accuracy of the Transit-type navigational system.

Optical Doppler systems were discussed in a paper by R. G. Franklin and D. L. Birx, another by W. C. Reisener Jr., all of Franklin Institute Labs, and a third by R. H. Norton and R. H. Wildey of JPL. The latter authors believe that an intrinsic variability (approximately ±200 fps) in the observer's measured optical Doppler velocity imposes a fundamental limitation more serious than that due to the instrumentation errors.

The fact that the infrared image of the earth can be observed from a point in space and used to establish the horizon, or local vertical, under all conditions of the earth's illumination and weather conditions, has led to the development of practical devices for use in advanced space vehicles. These devices can also be used in the vicinity of the moon and the planets. E. M. Wormser and M. H. Arck of Barnes Engineering discussed the concepts employed in the design of horizon sensors for a number of different applications. It was shown that no "universal" instrument seems likely, and each sensor will be designed for a particular application.

At luncheons of the ARS Guidance, Control, and Navigation Conference, guest speakers addressed audiences seated under pleasant oaks on Stanford's campus. Left, C. Stark Draper, director of MIT's Instrumentation Laboratory, talks on "Space Achievements and Instrumentation." Center, L. I. Schiff, head of Stanford's Physics Dept., discusses the July conference at the University called by NASA to propose space experiments on relativity theory. Right, Helmut Schlitt, manager of Bell Aerosystem's Inertial Development Laboratories, gives "Some Thoughts Concerning our Progress in Aerospace Technology."

D. R. McMorrow et al. of GE discussed a particular design for a star tracker having application to space-vehicle attitude control and navigation. The mechanical scanner uses vibrating reeds, which provide long life and low power consumption.

An optical synchro based on the use of polarized light and having an accuracy of better than 1 arc second, and having application to the precision alignment of aerospace systems, was discussed by R. O. Wyne of Chrysler.

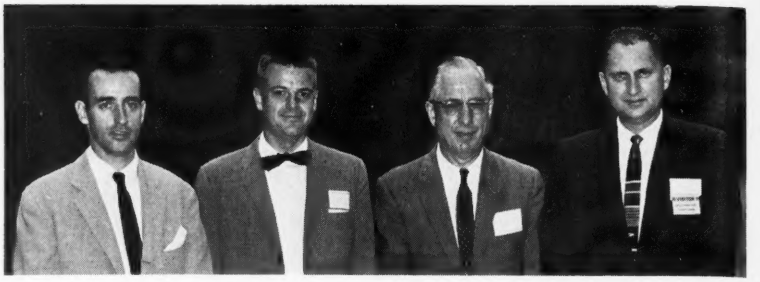
A. J. Khambata and R. A. Urban of Remington Rand Univac focused attention on the requirements for space-age computers by considering a hypothetical small, low power digital computer with a processing capability 10 times greater than a typical present-day, large-scale computer. It was shown that further development of transistors, tunnel diodes, deposited thin films, and microtronic circuits can be expected to make such computers practical before 1970.

Injection of High Interest

The session on Injection and Reentry Guidance chaired by R. F. Hoelker of Marshall Space Flight Center was of exceptional interest. The injection-guidance problem was formulated in a highly sophisticated manner in a paper by W. E. Miner and D. H. Schmieder and another by D. H. Schmieder and N. J. Braud, all of Marshall Space Flight Center. They discussed optimization of the guidance mode for the case where thrust variations in flight do not allow linear treatment. The problem of efficiently guiding the multistage Saturn vehicle, while allowing an engine-out capability of its eight-engine first stage, suggested the need for such an approach. A thorough understanding of the interrelationships of measuring, guiding, and controlling, coupled with a straightforward, though novel, analytical approach involving the methods of the variational calculus, have yielded a type of guidance mode which the Marshall scientists call "path-adaptive." This name is derived from the property of the guidance mode to provide, at any time in flight, a reference path which links in an optimum way the current conditions to a proper set of terminal conditions.

Wayne Schmaedeke and George Swanlund of Minneapolis-Honeywell discussed the case where the thrust magnitude is predictable except for small variations about the nominal, which allows linear treatment of the problem.

P. C. Dow et al. of Avco discussed two automatic re-entry guidance concepts for super-orbital velocities, one called "prediction guidance" and the other called "apparent target guidance." They defined a "survival phase" during the initial re-entry period where the prime objective is to prevent skip-out occurring and at the same time prevent excessive loads.



Behind the planning and fine program for the GCN Conference were, right to left, James Farrior of Lockheed, chairman of the ARS Guidance and Control Committee; Donald LeGalley of STL, program chairman; Robert Cannon of Stanford Univ., program vice-chairman; and Daniel DeBra of Stanford, in charge of local arrangements.

Drag modulation was the basis of a satellite landing-control system discussed by J. E. Hayes of Avco and W. E. Vander Velde of MIT. They stated that the Avco drag brake can perform a number of functions normally requiring other equipment and subsystems, such as maintain attitude control in orbit, initiate re-entry, dissipate re-entry heat by radiation, and accurately control the landing point.

Planetary probes and lunar-landing systems were covered in a session chaired by H. H. Haglund of JPL. The earth's rotation and the relative motion of the earth with respect to other bodies create a launch-on-time problem. This was discussed by C. E. Kohlhase of JPL. It was shown that the inability of the vehicle to perform severe maneuvers greatly limits the launch window. Parking orbits can be used to relieve geometric constraints by variation of the parking-orbit interval.

R. Rosenbaum of MIT discussed the problem of controlling the longitudinal range of a lifting vehicle entering the atmosphere of a planet at a small re-entry angle. A range-prediction system was proposed which makes use of an equilibrium-glide trajectory, rather than an arbitrary nominal trajectory. The lift-to-drag ratio can be set on the basis of a comparison between desired and predicted range, either continuously or at intervals along the trajectory.

According to R. K. Cheng and I. Pfeffer of STL, a lunar-landing velocity of about 20 fps will permit survival of sensitive instruments which can telemeter information back to earth for analysis. Landing would be kept within a predesignated area by mid-course corrections based on radio tracking from earth-based facilities. Using optical sensors to determine attitude and a radar altimeter to determine height, as indicated in the sketch on page 34, the vehicle begins retro-thrust at approximately 40-mi. altitude with a descent velocity of approximately 8000 fps. Vernier engines fire at approximately 6 mi. altitude. The vehicle is allowed to fall to the surface from a height of about 30 ft.

W. C. Marshall of Minneapolis-Honeywell gave a treatment of calculus of perturbations, or linear-prediction theory, applied to the disturbed motion of a lunar vehicle with respect to a nominal or reference trajectory.

"Orbital Operations" was the subject at the session presided over by P. J. De Fries of Marshall Space Flight Center. L. J. Knudsen of Autonetics addressed himself to the subject of a guidance system based on "generalized correlated velocity." This technique, he stated, is applicable to a wide variety of problems. The velocity to be gained is the difference between the vehicle velocity and the desired velocity correlated to the vehicle position. This vector can be driven to zero through vehicle steering and thrust cutoff.

Rendezvous Problems

The need to bring two satellites together in space poses some special problems. These were discussed by W. Schroeder of STL. He assumed the primary sensor was radar aboard the chaser, delivering range and range rate. His coarse maneuver phase, which establishes a closing trajectory, was followed by a braking phase to decrease the closing rate and a vernier phase to obtain the desired docking accuracy. J. W. Ward and H. M. Williams, also of STL, discussed details of docking dynamics.

By proper choice of the inclination and period of orbiting vehicles or

orbiting launch-base complexes, a "rendezvous compatible" orbit can be established which provides two rendezvous launch possibilities a day from a single launch site. Station keeping for such a satellite was discussed by R. S. Swanson et al. of Northrop.

Two sessions, chaired by E. T. Reeves of STL, were devoted to space-vehicle attitude sensing and control. H. Patapoff of STL discussed a new technique for the analysis of reaction-jet attitude-control systems. This technique termed the rate diagram, is based on examination of vehicle attitude rate at thrust termination as a function of attitude rate at thrust initiation. It provides a sharp insight into system performance.

C. Grubin of Nortronics discussed a generalized two-impulse scheme for reorienting a spin-stabilized vehicle; and R. S. Gaylord and W. N. Keller of STL and P. R. Dahl et al. of Aerospace presented papers on control systems utilizing reaction jets. The influence of system parameters on performance was examined.

P. H. Savet of Arma discussed attitude control of satellites under the influence of the forcing functions due to high orbital eccentricity. R. J. McElvain of STL considered the effect of solar radiation satellite attitude control. Problems of dynamic cross-coupling between reaction wheels and basic missile dynamics were discussed by D. DeBra of Lockheed and R. H. Cannon of Stanford.

Then A. G. Buckingham of Westinghouse Electric presented mechanization and design parameters for an attitude-control system which derives control torques by magnetic interaction with the earth's magnetic field. Reaction-control A-C servomotor design was the subject of a paper by T. Bernstein and D. R. Howard of STL. Trade-offs with respect to weight and power consumption were discussed. M. D. Olstad and R. Grunberg presented a paper concerned with the synthesis and mechanization of the attitude-control system of a spinning manned space station.

Fundamental Limitations

R. E. Roberson, a private consultant, chaired a very interesting "special topics" session in which M. Kayton of Litton discussed some of the fundamental limitations on one's ability to detect "absolute" acceleration and rotation velocity, thereby establishing bounds beyond which there are inherent physical barriers to the more precise measurement of these quantities. In rotation an ultimate bound may be 10^{-11} deg per hr, but in the range 10^{-11} to 10^{-4} deg per hr many small effects must be included in the mechanization to permit the realization of this accuracy. Corresponding boundaries for acceleration are 10^{-7} to 10^{-5} g.

Some of the modern trends of control theory were evident in the three papers of A. Peske and M. Ward, and D. Lukes, all of Minneapolis-Honeywell, and F. Faulkner of the Navy's Postgraduate School in Monterey, Calif. The first of these concerned the application of adjoint techniques to the error analysis of trajectories, the others the application of the Pontryagin Minimum Principle to path control during powered boost. These three papers were directed primarily at providing methodologies for treating certain classes of guidance and control problems, and did not include definitive results on particular cases.

Five interesting and informative papers were presented at the session on adaptive control systems chaired by D. P. Chandler of Autonetics. This young but rapidly growing field will have important bearing on future design concepts of guidance and control systems requiring complex control processes.

B. Widrow of Stanford Univ. pointed out that adaptive control systems have the capability of giving near-optimum performance in spite of changing command and changing dynamics of the controlled processes. This capability was effectively demonstrated by a pattern-recognizing device utilizing a matrix of "memistors"— circuit elements whose resistance can be varied by electroplating. This matrix could be instructed to recognize a given pattern, which the system then remembered despite subsequent instructions. This demonstration was a highlight of the session.

J. C. Hsu of Bell Telephone Laboratories discussed a class of adaptive control systems which he called "Decision Adaptive Control Systems." He suggests discrete-step compensation methods of adaption for systems with limited process measurement time.

W. W. Wierwille of Cornell Univ. discussed the use of frequency-domain techniques and their application to time-variable networks in the analysis of adaptive-control systems. He formulated the difficulty of fast adaption into the uncertainty principle, which relates quality of adaption to speed of adaption.

The paper by H. P. Whitaker and A. Kezer of MIT outlined the possibility of increasing system reliability by

John Moore, president of NAA's Autonetics Div. (second from left), joins the audience at banquet night of the GCN Conference in applauding the work of Daniel DeBra on local arrangements. Featured speaker at the banquet, Moore gave an analysis of problems faced by major producers of guidance equipment, as well as recounting some of his interesting personal experiences in early guidance projects. To his right is Fred Terman, vice-president and provost of Stanford Univ., and to his left, Howard Kindsvater, president of the ARS Northern California Section; Willis Hawkins, general manager of Lockheed Missiles and Space Co., who was toastmaster for the evening; Donald LeGalley of STL, program chairman for the meeting; and R. E. Roberson, who chaired a session.

utilizing adaptive servos and redundancy. The model-reference technique for determining adaption information was described along with an example showing a capability of maintaining near-optimum control throughout the transient response of the overall system. Professors Whitaker and Widrow then proceeded to a lively discussion of limiting speed of adaption.

W. R. Evans and J. H. Jerger of Aeronutronic presented a unique method of generating autopilot signals independent of undesirable bending-mode information. The method utilizes accelerometers distributed along a missile and is not dependent on knowledge of the bending modes. The nature of the stabilization problem of a flexible missile was effectively demonstrated by means of a model.

Of special interest to future design was a session on exotic inertial components, chaired by R. H. Cannon of Stanford. This session gave participants a look at sensors that are still in the research or early developmental stages. Most "exotic" of the devices discussed was the nuclear gyro, which makes use of the perfect inertial properties of atomic nuclei, thereby circumventing all the problems of attaining quasi-perfect geometry, dimensional stability, homogeneity, etc. associated with instruments based on macroscopic inertial elements. The device would operate at liquid-helium temperatures so that the nuclei, once aligned, would have long relaxation times. W. H. Culver of the Institute for Defense Analysis, in describing the device, proposed using the helium-three isotope in a spherical container, which would have the required properties of polarity and would remain gaseous even at liquid-helium temperatures. He pointed out the formidable problems of providing sufficient magnetic shielding, of initially aligning nuclei, and of picking off the nuclear directions.

At the macroscopic level, research activity in supporting spherical gyro rotors in both electrostatic and supercooled-magnet fields were reported. Both approaches provide gyros of extreme accuracy and long life by supporting a spinning inertial sphere in vacuo by strictly radial forces.

A. Nordsieck of GM Research Laboratories (Santa Barbara, Calif.), inventor of the electrostatically supported gyro, described a hollow spherical rotor supported by electrostatic forces via a servo system of the passive type. An optical pickoff works on a light and dark pattern on the rotor, and controls a servo system to null the case with respect to the sphere. Sources of error are fewer than in conventional gyros, consisting of axial mass unbalance, any current drag moments due to stray magnetic fields, and (most important) imperfect geometry, such that the support force vectors do not pass quite through the center of the sphere. Test data presented indicate that this device is nearing the point of operational development.

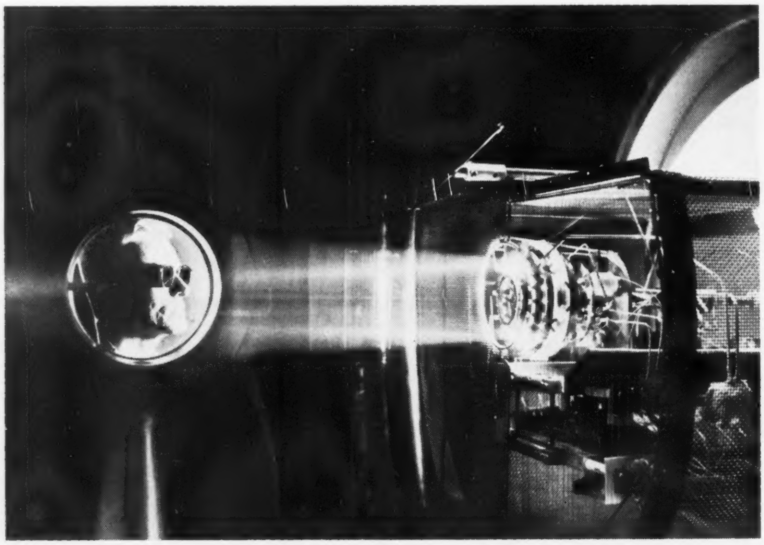
The support of a rotor by magnetic fields under cryogenic conditions was described by J. Harding of JPL. The rotor is of a material, such as niobium, which becomes superconductive at liquid-helium temperatures, and hence is perfectly diamagnetic, so that strictly radial constraint is provided without a servo system and without power input. Problems of geometry and balance are similar to the electrostatic device; and, in addition, trapped flux must be eliminated from the rotor. Harding stressed the fact that rotors at very low temperature have perfect dimensional stability and high rigidity.

T. A. Buchhold described an experimental prototype niobium-rotor gyro, including optical pickoff and electromagnetic torquer, which has been under development for some time at General Electric. Dr. Buchhold also pointed out the possibilities of cryogenic accelerometers.

The proposal by Stanford Univ. to use a gyroscope of extreme accuracy to demonstrate the general theory of relativity was explained in theory by L. I. Schiff in a general luncheon address and described in more detail by W. H. Fairbank and M. Bol of the University. For a gyro in an earth-orbiting satellite, the relativity effect would produce a rotation of the spin momentum vector of 7 sec of arc per year. The gyro would, of course, have to be appropriately more accurate than the effect. As a bonus, if sufficient accuracy was attained, a second-order effect of about 0.2 sec of arc per year might be observed.

The use of a superconducting gyro in an orbiting astronomical observatory to carry out the Schiff experiment was described by Fairbank, who announced his recent discovery that flux in a superconductor is quantized. Early experiments on a high-accuracy radioactive readout method were described by Bol.

The Society is indebted to D. P. LeGalley of STL, program chairman, and to many other individuals who, through their contributions of time and effort, made the conference a success, and to Stanford Univ., which made its excellent facilities available for the meeting.



Hughes Shows Ion Engine Developed for NASA

This first of what Hughes Aircraft's research staff hopes will become a family of ion engines for spacecraft performed in a vacuum tank recently as part of a public demonstration of the company's work on advanced propulsion. Before mid-year, Hughes delivered to NASA a prototype cesium-ion engine, like the one shown here being demonstrated, which performed to specifications. Progress in the Hughes development program for NASA was reported by Etter et al. of Hughes Research Laboratories at the ARS-IAS joint meeting on the West Coast in June.

An
Invitation
to
Engineers,
Scientists,
and Their
Families

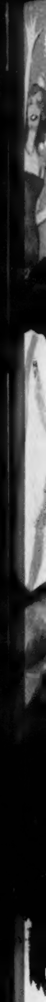
FIRST CLASS
PERMIT NO. 1524
SAN DIEGO, CALIF.

BUSINESS REPLY MAIL
No Postage Stamp Necessary if Mailed in the United States

POSTAGE WILL BE PAID BY

GENERAL DYNAMICS | ASTRONAUTICS
POST OFFICE BOX 1128
SAN DIEGO 12, CALIFORNIA

PERSONAL AND CONFIDENTIAL
ATTENTION: MR. R. M. SMITH
MAIL ZONE 130-90



Er
nc
op
th
Sa
its
ye
te
ar
ac

If
th
cc
m
ve
tia

Engineers and scientists at General Dynamics | Astronautics enjoy not only the immeasurable rewards of participating in the development of this nation's most advanced space systems, but also the added bonus of living and raising their families in resort-like San Diego, California. San Diego's climate is near-perfect, and its ideal location permits almost any sort of family recreation the year around. Indeed, on the first day of summer last year, the temperature was 78 degrees; on the first day of winter, 76. Schools are excellent and uncrowded; cultural attractions are abundant; advanced educational facilities are constantly being expanded.

If you are an experienced engineer or scientist, just a cut above the average, we'd like to tell you more about our company, our community, and how both might fit into your future. You'll find more information on the back of this page. There is also a convenient inquiry card which will receive immediate and confidential attention. Why not mail it today? No obligation, of course.

If the inquiry card has been removed, or if you wish to furnish or request more detailed information, please write to Mr. R. M. Smith, Industrial Relations Administrator-Engineering, Mail Zone 130-90, General Dynamics | Astronautics, 5702 Kearny Villa Road, San Diego 12, California. (If you live in the New York area, it may be more convenient to contact Mr. T. Cozine or Mr. E. Hart, General Dynamics | Astronautics, One Rockefeller Plaza, New York City, Telephone CIrcle 5-5034.)

GENERAL DYNAMICS

ASTRONAUTICS

FORMERLY CONVAIR/ASTRONAUTICS

PROFESSIONAL PLACEMENT INQUIRY

This card may be folded and sealed or stapled and mailed in complete confidence. It will enable the professional staff at General Dynamics|Astronautics to make a preliminary evaluation of your background. A personal interview can be arranged in your city by appointment. Every completed inquiry will be acknowledged.

NAME ____________________

STREET ADDRESS ____________________

CITY & STATE ____________ TELEPHONE ____________

NEAREST MAJOR CITY (IF APPLICABLE) ____________________

COLLEGE GRADUATE: YES ☐ NO ☐ DEGREE: BS ☐ YR____ MS ☐ YR____ PH D ☐ YR____

MAJOR SUBJECT:

AERONAUTICAL ENGINEERING ☐ MECHANICAL ENGINEERING ☐
ELECTRICAL ENGINEERING ☐ MATHEMATICS ☐
ELECTRONIC ENGINEERING ☐
CIVIL ENGINEERING ☐ PHYSICS ☐

OTHER ____________________

FOLD

EXPERIENCE:

PRIMARY SPECIALTY ____________ YRS. ______

SECONDARY SPECIALTY ____________ YRS. ______

ADDITIONAL COMMENTS, IF ANY, CONCERNING YOUR JOB INTERESTS:

PLEASE SEND GENERAL DYNAMICS|ASTRONAUTICS RECRUITMENT BROCHURE: A-11 ☐

MHD Symposium

(CONTINUED FROM PAGE 41)

Cole stressed the vital importance of communication between the scientist and the layman through the vast media of the press.

Daniel Bershader of Lockheed and Stanford presented findings of a study on an argon-shock-layer plasma performed with the use of a 3-in. combustion-driven shock tube. Special attention was focused on heat-transfer verification of the derived theory. Within the range of parameters studied, the behavior of the argon plasma shock layer was consistent with the predictions of aerodynamic and radiative heat-transfer theory and with observations on radiative cooling.

Alan W. DeSilva, John M. Wilcox, William S. Cooper III, and Forrest I. Boley of the UC Lawrence Radiation Laboratory presented one of the nicest experimental studies of the symposium. The work concerned Alfven-wave propagation in a cylinder filled with a plasma of ionized hydrogen with a torsional oscillation excited by a radial current flow at one end, driven from an external circuit. The diagram on page 41 illustrates their apparatus. Observations were clarified and the experimental results were good.

Ernst Stuhlinger, chairman of the ARS Electric Propulsion Committee and chairman of the fourth session, made a strong plea for the solidification of the group under the banner of magnetofluidmechanics. He presented von Karman's classic argument that "fluid" covered both gases and liquid metals, while hydro means water; also mechanics includes dynamics and statics and thus more completely covers the sphere of interest.

The paper by Sherman-Sutton of General Electric investigated the combined influence of tensor conductivity, fluid viscosity, and segmented electrodes for an MHD generator. Calculations showing the influence of $\omega_0\tau$ (the product of electron frequency and electron mean free time), H_a (Hartman number), and K (generator loading parameter) on the flow were presented. In particular, the fact that an increase of $\omega_0\tau$ increased the generator efficiency was brought to light. This unexpected result was shown to be due to velocity profile distortion caused by increasing $\omega_0\tau$. The segmented electrodes were used to alleviate the Hall effect prevalent in this generator's operating range.

Demetriades and Ziemer of Norair Div. of Northrop gave a joint presentation of their theoretical and experimental study of the acceleration of a plasma stream by continuous JxB, or Lorentz, forces. The novel approach

Founding member of ARS, G. Edward Pendray, at the dais, toastmaster for the banquet given the first day of the three-day MHD conference, gives some personal impressions of the growth of the space field, and prepares to introduce the evening's speaker, Ira W. Cole, dean of Northwestern's Medill School of Journalism, who discussed "Science and the Press." At the head table, from left, are John Fenn of Princeton, Project Squid director; Charles Miesse of Armour Research, president of the ARS Chicago Section; William Bradford, dean of Northwestern's Summer Sessions; Dean Cole; Dr. Pendray; Ali Bulent Cambel, director of Northwestern's Gas Dynamics Laboratory and co-chairman for the meeting; Harold B. Goddess, Northwestern's dean of engineering; and Thomas P. Anderson of Northwestern, a co-chairman of the meeting.

of this paper was the use of developing the theory in terms of easily measured quantities such as thrust. Measurements yielded acceleration efficiencies as high as 42%. Following this paper there was a heated discussion concerning the $\dot{m}$ (mass rate of flow) used; some participants expressed the thought that a jet-pump effect might have been present. A sketch of their test setup appears on page 41.

Low-Temperature Accelerations

J. K. Richmond et al. from Boeing presented an interesting paper concerned with the loss mechanisms (electrode boundary layer and Hall reduction) for low temperature plasma accelerations.

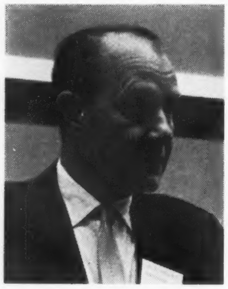
One highlight of the symposium was the MHD panel discussion, held on the second evening. George Sutton rivaled Mort Sahl in the opening moments of his review paper on "Magnetohydrodynamic Power and Propulsion." This paper, co-authored by Per Gloersen, also of General Electric, was a noble effort covering an impossible task in 45 min.

Alan Penfold, chairman and moderator, then took over and asked each of the panelists to discuss briefly problem areas of prime importance to them. Stewart Way of Westinghouse touched on purity of flow for wind-tunnel applications and flow losses due to long narrow channels. George P. Wood of

Published Results with Crossed-Field Accelerators

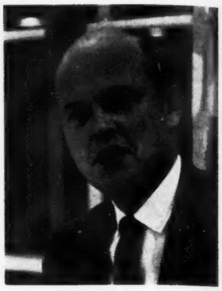
(From "MHD Power and Propulsion," a review—ARS Preprint 2005-61—by Sutton and Gloersen of GE Space Sciences Laboratory)

	Wood (27)	Ragusa & Baker (28)	Demetriades (29)
Gas	$N_2(C_s)$	A	A, N_2, Air
T_o, °K	7000	4000	-------
Mass flow, gm/sec	2.5	2.9	1.4
Inlet Mach no.	2	2.7	-------
Inlet Velocity, 10^3M/sec	3	1.5	4
Accelerator length, cm	7	8	--------
Cross section Area, cm^2	1	3.6	6.5
Magnetic field, gauss	11,000	6100	1700
Electric Field, v/cm	30-50	30-36	10-23
Electrical Conductivity, $ohm^{-1}cm^{-1}$	200	100	--------
Max. Current, amps	----	58	1000
Current density, $amps/cm^2$	6-30	---	--------
Magnetic Interaction Parameter	.07	---	--------
MHD Thrust, lb.	.54	.07	1.1 (3)
MHD I_{sp}, sec	100	---	350 (1400)
Max. Conversion efficiency	70	50	40



Ritchey

Left, ARS President Harold Ritchey of Thiokol Chemical makes introductory remarks to open the MHD meeting. Right, Dean Ira W. Cole of Northwestern's Medill School of Journalism addresses the banquet audience on "Science and the Press." Dean Cole stressed the importance of the scientist and engineer as an expositor, a teacher in a democratic society. He prefaced his comments with this quotation, which comes from the book, "Elements of Natural Philosophy," printed in Philadelphia in 1808: "The great object of science is to ameliorate the condition of man, by adding to those advantages which he naturally possesses—If, then philosophical knowledge be of such essential advantage in the general pursuits of society, it surely becomes highly expedient to diffuse it (an understanding of science) in such a manner as to enable every class to obtain some portion of the whole."



Cole

NASA-Langley showed a slide of a huge engine whose main problem for space applicability was the magnet size. Alfred E. Kunen of Republic Aviation thought the standardization of thrust and mass flow measurements was badly needed. He also advocated, and was seconded by many in the audience, that the specific impulse should be defined by $Isp = f/\dot{m}$ rather than the use of light front correlations. Sargent Janes, of Avco-Everett Research Laboratory, also touched on wall-loss problems due to boundary layer buildup. He mentioned the bright outlook for magnetic containment in three areas. The panel discussion was maneuvered from one important topic to another most ably by Dr. Penfold. The audience was invited to participate and the evening was most fruitful for all those present. Topics of discussion were, to mention a few-measurement methods, test facilities, propulsion-device lifetime, material problems, containment both viscous and magnetic, RF generated plasmas, the real reason for MHD propulsion, and generator applications. This was agreed upon by most as the best session of an excellent symposium.

Viscous Flow Analyzed

The last day's proceedings were opened by a rigorous analysis of a viscous flow between rotating cylinders in the presence of a strong axial magnetic field by William H. Reid of Brown Univ. He presented a nondissipative and then a dissipative analysis for small magnetic Prandtl number. The onset of instability was determined and compared for various rotation combination and field strengths.

Hen-ichi Kusukawa of Rensselaer Polytechnic considered an inviscid compressible fluid with small conductivity flowing steadily past a slender body of arbitrary cross section in the presence of an applied magnetic field parallel to the uniform flow. By using the slender-body approximation, he was able to determine the character of the velocity and magnetic fields and obtain the drag and lateral force exerted on the body.

James A. Fay of MIT presented some aspects of boundary-layer-type flows in gases which were partially or wholly ionized. The change in transport properties due to ionization were estimated and the resulting effects on heat transfer in a monatomic gas were determined. It was found that momentum layers of constant thickness can be expedited in practical MHD devices along any insulating surface normal to an applied magnetic field.

J. C. Crown of United Aircraft analyzed the fluid and field characteristics in a steady quasi-one-dimensional flow of an electrically conducting, compressible, inviscid, isotropic fluid in the presence of crossed electric and magnetic fields. This paper is an important extension of earlier quasi-one-dimensional flow. The solution was a numerical one for $T = C$ and $V = C$ flows, looking at the effect of area variation of the channel.

The papers presented at the seven sessions are in the process of being published by the Northwestern Univ. Press.

As the Fourth Biennial ARS-NU Gas Dynamics Symposium came to an end and the participants prepared to leave Evanston, there seemed evident a sense of intellectual satisfaction. In his opening remarks, ARS President Harold Ritchey had pointed out that the ARS-NU Gas Dynamics Symposium was the prototype of the many successful ARS specialists conferences now in existence. There was no question that the prototype itself had not become absolute. ♦♦

Co-chairmen for the ARS-Northwestern Univ. 4th Biennial Gas Dynamics Symposium on Magnetohydrodynamics—from left, Milton M. Slawsky of AFOSR, head of the ARS Magnetohydrodynamics Committee, Thomas P. Anderson of Northwestern, and Ali Bulent Cambel, director of Northwestern's Gas Dynamics Laboratory—confer just before the meeting gets under way at the University's Technological Institute.


1 2 3 4 5 6 7 8

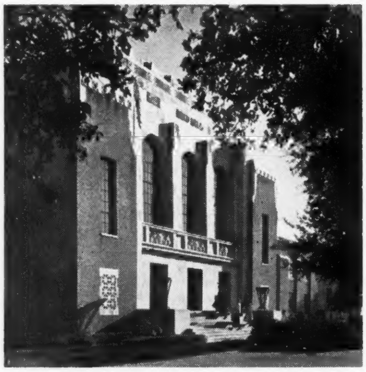
ARS news

ARS Solid Propellant Conference Set for Waco January 24–26

The third annual ARS Solid Propellant Conference will be held on the campus of Baylor Univ., Waco, Tex., Jan. 24–26. Purpose of the conference, sponsored by the ARS Solid Rocket Committee, is to focus attention on certain critical research problems in solid propellants and solid rockets, in order to define more clearly those areas in which more intensive investigation is warranted.

Tentative session topics for the meeting are: Nondestructive testing; explosive classification of motors; use of electronic computers in research, design, and development of solid-rocket motors; propellant processing; rocket motors for meteorological sounding purposes; high-performance solid motors; fabrication of inert components for large solid motors; gas dynamics and heat transfer; and effects of environment on rocket-motor operation.

Technical Program Chairman for the conference, expected to attract an attendance of more than 600, is G. Daniel Brewer of Grand Central Rocket Co., chairman of the ARS Solid Rocket Committee. R. K. Moore of Rocketdyne is general chairman of the meeting, which is being held in Waco at the invitation of the ARS Central Texas Section, headed by F. R. Gessner Jr.



Waco Hall on Baylor Univ. campus, scene of ARS Solid Rocket Conference in January.

SECTIONS

Alabama: In July, **Albert L. Nowicki,** chief of the Dept. of Cartography, U.S. Army Map Service, Washington, D.C., addressed a joint meeting of this Section and the Rocket City Astronomical Association on "Topographic Mapping of the Moon." Making maps of the moon, Nowicki said, can give clues to its nature, for example, its density. He explained stereoscopic photography of the moon, making use of its wobble; and also how mapping calls for pinpointing positions. There must be built a reference for this purpose with lines of 0 deg, like the equator and the Greenwich line. The so-called point of "0" vibration determines the vertical line, while a small crater on the moon's surface, "Musting A," places the horizontal. All positions on the moon are plotted in reference to these. Nowicki said there are those who question whether the moon's craters really exist. He himself, he stated, does not know the answer. Many slides were shown.

In August, **Audouin Dollfus,** of the Paris Observatory, Meudon, France, spoke to a joint meeting of the Section and the Rocket City Astronomical Association on "Atmospheric and Surface Features of Mars and Venus." It is a prime objective of the Paris Observatory, he stated, to balloon-raise a telescope above most of the earth's atmosphere to achieve clearer observation of the planets, principally Venus and Mars. The gondola for the telescope is spherical and is made of aluminum-alloy sheet, polystyrene-coated, wrapped around a light aluminum framework. Using this balloon-capsule arrangement, Dr. Dollfus made a number of ascensions for planetary observation. Two years ago he made a flight to 14 km. He had planned another flight for this past September.

Dr. Dollfus told of a new balloon technique now under development. This technique would consist of single balloons placed at intervals along a cable with the cable running through the balloon centers. The balloon's bottom section would be secured to the cable while the upper section could slide up along the cable when the balloon expanded.

—**J. Frank Rushton**

Allegheny (Probationary): Officers of this recently formed Section are Albert M. Jacobs, president; William H. Fuller, vice-president; Mary D. Eirich, secretary; and David L. Day, treasurer. Guest speaker at the Section's dinner meeting in August was **A. M. Rothrock,** NASA staff scientist, who discussed "NASA Space Programs." He reviewed the space projects already in progress as well as long-range plans for lunar landing and interplanetary exploration.

—**Mary D. Eirich**

Atlanta: The Section's new officers are as follows: A. P. Pennock, president; E. F. Cox, vice-president; J. W. Tatom, secretary; and F. M. White Jr., treasurer.

—**A. P. Pennock**

Carolina (Probationary): Officers of this new and probationary Section include Ross T. Radey, president; J. Frank Coneybear, vice-president; F. David Parrott, secretary; and Ralph J. Blalock Jr., treasurer.

Cleveland-Akron: New officers of the Section are as follows: Harold W. Schmidt, president; Charles M. Stockman, vice-president (Akron); James A. Rudy, vice-president (Cleveland); and Edmund R. Jonash, secretary-treasurer.

—**Edmund R. Jonash**

Dayton: The Section's new slate of officers is—Ralph Hodge, Aeronautical Systems Div., Wright-Patterson AFB, president; Gene Babb, Hughes Aircraft, vice-president; Gus Schwarz, AF Logistics Command, secretary; and George Gardner, Republic Aviation, treasurer.

—**A. G. Liefke**

National Capital: In August, the National Capital Section held its regular luncheon meeting at the Hotel Washington Terrace. The guest speaker was **Maj. Gen. Clyde H. Mitchell,** deputy chief of staff, Procurement and Materiel. Attendance was over 100 persons.

—**E. Paul Jackson**

New Mexico-West Texas: The Section started its fall season with the installation of new officers at a dinner

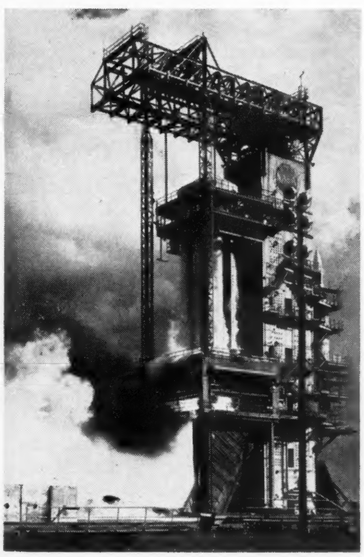
meeting held at the Town and Country restaurant at Las Cruces, N. Mex. The new officers are John L. McAdory Jr., president; Paul Arthur, vice-president; James Bunn, secretary; and Charles M. Johnson, treasurer. Dinner speaker was **Capt. Carter L. Bennet**, USN, commander of the U.S. Naval Ordnance Missile Test Facility at White Sands Missile Range, who discussed "Navy Operations at White Sands Missile Range."

Interesting programs are planned for the coming year, including tours of WSMR, Sunspot Observatory on Sacramento Peak, N. Mex., Holloman AFB, and the Physical Science and Research Center at New Mexico State Univ. Also included on the agenda are technical meetings and panel discussions by well-known experts and regular dinner meetings to which nationally known guest speakers will be invited.

—James Bunn

Tennessee: A symposium on Simulated Space and High-Altitude Testing of Rockets was held on June 28–29, under the joint sponsorship of ARO, Inc., and Aerospace Corp. Approximately 200 specialists in the rocket, missile, and space-vehicle fields

What They Saw



"They" was the ARS Alabama Section, which witnessed this static firing of the Saturn booster during a field trip to NASA's Marshall SFC late in August. The firing lasted 113 sec; noise level at the bunkers was about 120 db. The thrust level of the booster was at that time up to 1.3-million lb, and the unit had been static-fired more than 120 sec.

On the calendar

1961

Nov. 1–3	AFOSR International Conference on High Magnetic Fields, Massachusetts Institute of Technology, Cambridge, Mass.
Nov. 7–10	American Nuclear Society Hot Laboratory and Equipment Conference, Chicago, Ill.
Nov. 12–17	Conference on Medical and Biological Problems in Space Flight, Nassau, Bahamas.
Nov. 13–22	International Meteorological Satellite Workshop, arranged by the Dept. of Commerce Weather Bureau and NASA, Washington, D.C.
Nov. 14–16	AFOSR International Conference on the Exploding Wire Phenomenon, Boston, Mass.
Nov. 14–16	Northeast Electronics Research and Engineering Meeting, Commonwealth Armory and Somerset Hotel, Boston, Mass.
Nov. 30–Dec. 1	IRE Professional Group on Vehicular Communications Conference, Hotel Leamington, Minneapolis, Minn.
Dec. 3–7	AIChE Annual Meeting, Hotel Commodore, New York, N.Y.
Dec. 5–6	Conference on Status of Meteorological Rocketry at Texas Western College, El Paso Tex. Sponsored by Army Signal Support Agency and Schellenger Research Laboratory, Texas Western College.
Dec. 26–31	Annual National Meeting of the American Assn. for the Advancement of Science, Denver, Colo.

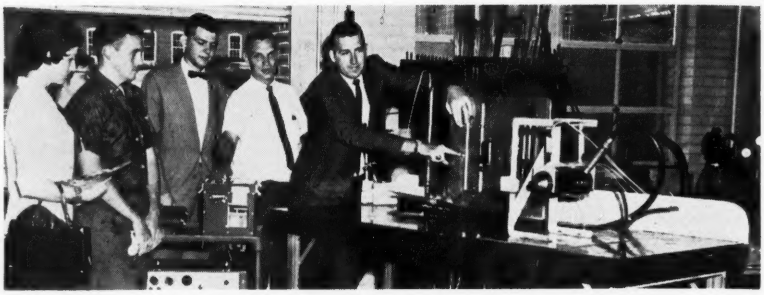
1962

Jan. 9–11	National Symposium on Reliability and Quality Control sponsored by IRE, AIEE, et. al., Statler-Hilton Hotel, Washington, D.C.
Jan. 24–26	ASME Thermophysical Properties Symposium, Princeton Univ., Princeton, N.J.
Jan. 24–26	**ARS Solid Propellant Rocket Conference, Baylor Univ., Waco, Tex.**
Feb. 4–7	AIChE National Meeting, Statler-Hilton, Los Angeles, Calif.
Feb. 7–9	IRE National Winter Convention on Military Electronics, Ambassador Hotel, Los Angeles, Calif.
Feb. 19	IAS Tracking and Surveillance of Aerospace Vehicles Meeting, San Francisco, Calif.
Feb. 27–March 1	Symposium on the Application of Switching Theory to Space Technology at Lockheed Missiles & Space Co., Sunnyvale, Calif. Sponsored by AF Systems Command, AFOSR, Office of Aerospace Research, and Lockheed M&SC.
March 14–16	**ARS Electric Propulsion Conference, Hotel Claremont, Berkeley, Calif.**
April 3–5	**ARS Launch Vehicles Structures and Materials Conference, Ramada Inn, Phoenix, Ariz.**
April 10–12	AFCRL Symposium on the Plasma Sheath—Its Effect Upon Re-entry Communication and Detection, New England Mutual Hall, Boston, Mass.
April 14–16	Second Conference on Kinetics, Equilibria, and Performance of High-Temperature Systems, sponsored by Western States Section of The Combustion Institute, at Univ. of California, Berkeley, Calif.
May 21–23	**ARS, AIEE, IAS, ISA, IRE National Telemetering Conference, Sheraton-Park Hotel, Washington, D.C.**
June 13–15	Annual Heat Transfer and Fluid Mechanics Institute, Univ. of Washington, Seattle, Wash.
June 23–27	**ARS Lunar Exploration Meeting, Pick-Carter and Statler-Hilton Hotels, Cleveland, Ohio.**
Aug. 15–17	**ARS, ANS, IAS Nuclear Propulsion Conference, U.S. Naval Postgraduate School, Monterey, Calif.**
Aug. 27–Sept. 1	Second International Congress on Information Process of International Federation of Information Processing, Munich, Germany.
Sept. 25–28	**ARS Power Systems Conference, Miramar Hotel, Santa Monica, Calif.**

attended the technical presentations and panel discussions on current and future testing-facility requirements and techniques. A. J. Zazzi of ARO, Inc., a charter member of the Section, served as associate chairman of the symposium. Col. G. A. LaRocca, also a Section member, served as associate chairman representing Arnold Center.

The speaker at our July meeting was **Dean N. W. Dougherty**, and his topic was "History and Education in India." During 40 years of service on the faculty at the Univ. of Tennessee, Dean Dougherty was the head of the Civil Engineering Dept., and later Dean of the College of Engineering. Following his retirement from the faculty in 1956, Dean Dougherty became a consultant to ARO, Inc. In 1959 the Dean visited India as a member of a team of educators to investigate the establishment of an institute of technology near Kanpur, India. Last fall, he returned to India to develop further plans for the institute. His talk and accompanying slides were of great interest and entertainment to those in attendance.

—T. J. Gillard



Tom Watts, at right, demonstrates a liquid-propellant rocket engine set up in a test cell.

STUDENT CHAPTERS

Auburn Univ.: Among several activities, the past year saw our Chapter participate in Auburn Univ.'s Village Fair, when students from statewide and local high schools visit the campus. The photos here depict some of our exhibits at the Fair. We also had on exhibit a self-contained environmental chamber, designed by David Wilson, to provide life-sustaining conditions for two squirrel monkeys for three days.

The Chapter has been holding regular meetings every other week. At each meeting we discuss pertinent business and usually show a film. The Chapter has also taken two field trips and had three guest speakers during the year—**Konrad Dannenberg** of NASA, **M. Wilkerson** of Pan American, Cocoa, and **Ray T. Patterson** of Martin-Orlando. The first field trip was to NASA, Huntsville, where we were taken on a tour of the Marshall SFC and, later in the evening, attended the annual meeting of the Alabama Section. The second field trip was to Ft. Ruckers, Ala. Here we had the opportunity of witnessing a firepower show.

—Harry E. Bates

TECHNICAL COMMITTEES

Joint Meeting of the ASME Professional Group on Underwater Technology and the ARS Committee on Underwater Propulsion will be held Nov. 29, 1961. The symposium has planned presentations on "Underwater Technology in Advanced Weapons Systems Design" by a prominent person in the Navy, "On Engineering of Underwater Vehicles" by Herman E. Sheets of GD/Electric Boat Div., and a presentation by a prominent scientist in oceanographic research, representing scientific interests in underwater technology. Another session contemplates three papers on underwater engineering.

Andy Conner, left, of Auburn shows visiting high-school students a model of a proposed interplanetary nuclear-pulse spacecraft.

Chicago Aquanaut Effects Lake Michigan Re-entry

Rocket research chemist Ted Erikson of the Armour Research Foundation became the first man to penetrate the free space of Lake Michigan and return successfully through the offshore boundary layer. An active member of the ARS Chicago Section, Erickson set world records for both distance (36.75 mi.) and duration 36.62 hr) in open water by swimming from Chicago's Burnham Harbor to Michigan City, Ind., on August 22nd —a kickoff of sorts for the ARS-Northwestern MFM Symposium that began the next day. Possible future missions include the deep-space penetration of Lake Michigan, from Evanston, Ill., to Benton Harbor, Mich.

Allegheny and Carolina ARS Sections Formed

"Allegheny" (Maryland) and "Carolina" (North and South Carolina) are the names of two recently formed ARS Sections serving probationary periods of one year.

CHANGE-OF-ADDRESS NOTICE

In the event of a change of address, it is necessary to include both your old and new addresses, as well as your membership number and coding, when notifying ARS Headquarters in order to insure prompt service. If you are moving or have moved, send the following form to Membership Dept., American Rocket Society, 500 Fifth Ave., New York 36, N.Y.

Name____________________

Membership Card No.__________ **Coding**__________

Old Address____________________

____

New Address____________________

____

1962 ARS Meeting Schedule

Date	Meeting	Location	Abstract Deadline
1962			
Jan. 24–26	Solid Propellant Rocket Conference	Waco, Tex.	Past
March 14–16	Electric Propulsion Conference	Berkeley, Calif.	Nov. 20
April 3–5	Launch Vehicles Structures and Materials Conference	Phoenix, Ariz.	Past
May 21–23	National Telemetering Conference	Washington, D.C.	Past
June 23–27	Lunar Exploration Meeting	Cleveland, Ohio	Feb. 15
Aug. 15–17	Nuclear Propulsion Conference	Monterey, Calif.	March 19
Sept. 25–28	Power Systems Conference	Santa Monica, Calif.	May 21

CORPORATE MEMBERS

Aerojet-General has expanded its underwater activities and split the former Anti-Submarine Warfare Div. into two independent units—the Oceanics Div. and the Torpedo Div . . . Air Products, Inc., has changed its name to **Air Products and Chemicals, Inc.** . . . **Atlantic Research** recently merged with Flight Sciences Laboratory, Inc., Buffalo, N.Y., via an exchange of stock. FSL, engaged in research and advanced engineering in aeronautics and astronautics, will be operated as an ARC group. ARC also acquired the National Northern Div. of American Potash and Chemical Corp. . . . **Chrysler Corp.**'s Missile Div. has added a 22,000-sq ft facility, Melbourne, Fla., in support of its Cape Canaveral operations.

General Dynamics Corp. has announced the formation of a new division, General Dynamics/Telecommunication, Rochester, N.Y., and the unification of GD/Electronics and GD/Pomona. GD/Astronautics has merged its Engineering Reliability and Quality Control departments into a single unit, Reliability Control Dept. . . . Kearfott Div. of **General Precision** recently established the Kearfott Research Center, West Paterson, N.J. . . . **Hughes Aircraft** unveiled last September its "Shangri-La" for scientists—ultra-modern research laboratories nested high in the Santa Monica mountains where a 400-man scientific staff will work on a wide variety of space-age projects.

Special Metals, Inc., recently purchased the Metals Div. of **Kelsey-Hayes Co.** for $7.7 million . . . **Walter Kidde & Co.** has opened a technical consultation and service center in Miami, Fla. . . . Chance Vought Corp., a subsidiary of **Ling-Temco-Vought, Inc.**, and Sud Aviation of France have reached an agreement to aid each other in planned diversification programs . . . At **McDonnell Aircraft**, Kendall Perkings, vice-president, engineering, has asked that arrangements be made for hiring over 100 engineers per month until further notice in order to meet contractual obligations . . . **Minneap-**

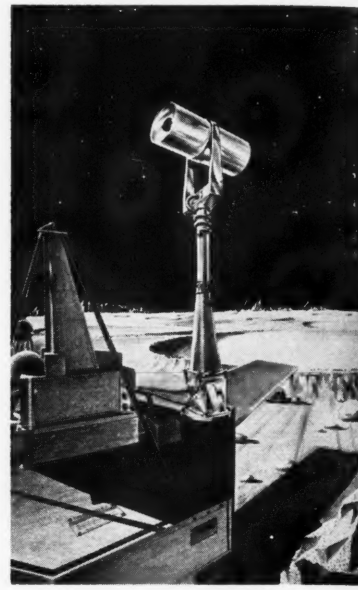
olis-Honeywell and British Aircraft Corp. have formed a joint organization, BAC-Honeywell Inertial Guidance-Europe, to develop, manufacture, and market inertial guidance systems in Europe.

North American Aviation has put into operation a microwave network that links the computer rooms of NAA's Autonetics Los Angeles and Rocketdyne divisions, the company's general offices, near Los Angeles International Airport, and the Atomics International (Canoga Park, Calif.) and Space and Information Systems (Downey, Calif.) divisions . . . **Raytheon** has announced it will expand its semiconductor operations and move its Massachusetts' silicon transistor, rectifier, and Circuit-Pak activities to Lowell, Mass, from the Greater Boston area . . . **Ryan Aeronautical** has established a European office in Paris at 102 Champs Elysees . . . **Sanders Associates** has opened a 4000-sq ft Advanced Communications Laboratory in Washington, D.C. . . . **United Aircraft's** Norden division's Ketay Dept. is being transferred to Norwalk, Conn. . . . **Wyle Laboratories** has acquired all the stock of Ransom Research, Inc., and Ransom Systems, two California firms, in exchange for 30,000 shares of WL's stock. ♦♦

Manned Space Flight Subject Of Bell TV Program Nov. 24

"Crossing the Threshold," the biography of a hypothetical manned orbital flight, will be presented by the Bell System over the NBC-TV network on Friday, Nov. 24, at 9 p.m. EST. The show will be the first of three 90-min Bell programs exploring space-age scientific frontiers. A second program will deal with U.S. space projects and their impact on the individual, the nation, and the world, while the third will cover other U.S. scientific plans, objectives and accomplishments.

For Action on the Moon



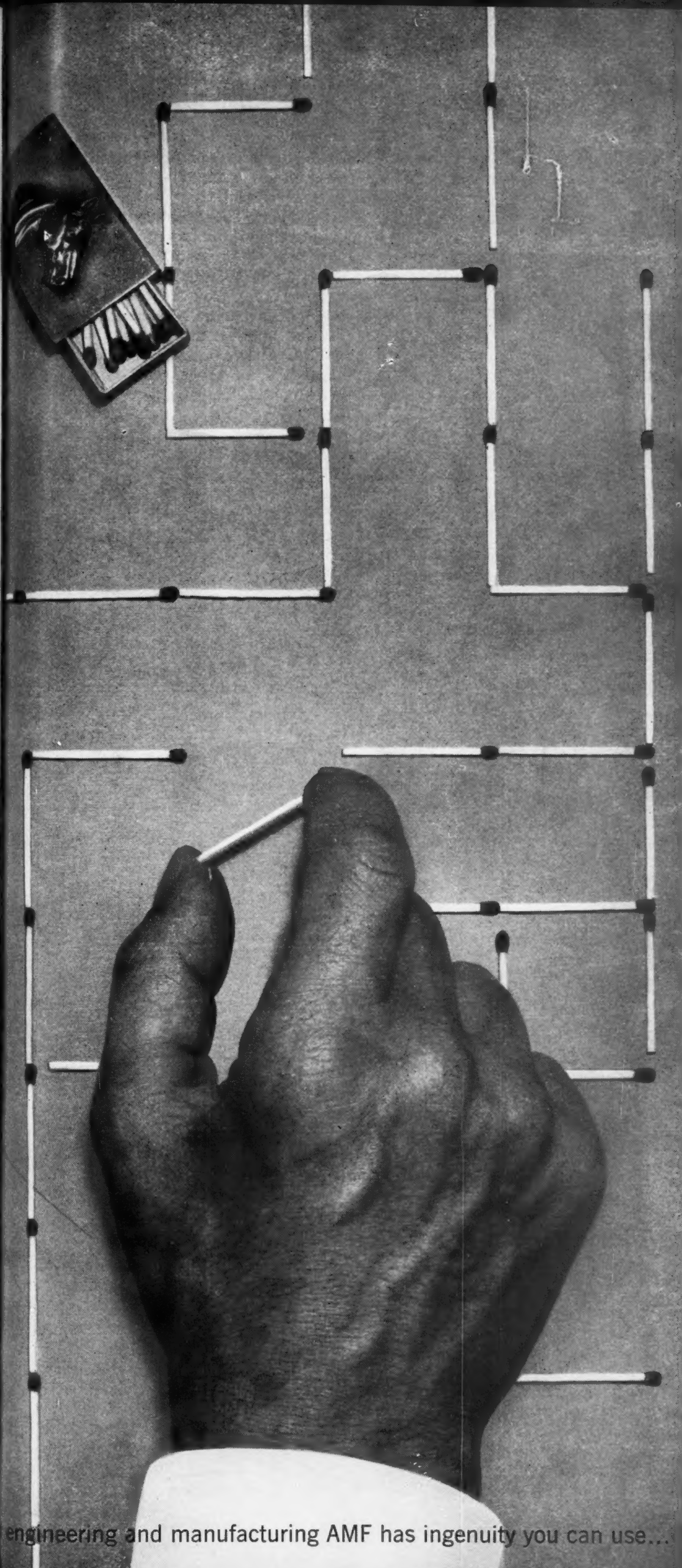
Depicted on a lunar vehicle, a General Mills' manipulator holds TV camera high as it scans surrounding area under radio control from earth. The company has delivered the first such manipulator to NASA's Jet Propulsion Laboratory for use in lunar-landing vehicle studies. Later units will be capable of picking up ground samples and other actions. The machine employs special motors, lubricants, bearings, insulation, etc.

Titan II Storable Propellants Handbook Issued by Air Force

A 160-page handbook on Titan II storable propellants—N_2O_4 and a blend of UDMH and N_2H_2—covering physical properties, materials compatibility, handling, safety, etc., has been prepared by Bell Aerosystems Co. and issued by the AF Flight Test Center, Edwards AFB, Calif., as AFFTC TR-61-32.

Energy Conversion Abstracts, NRL Reports Available

A volume of 548 abstracts from the literature on direct energy conversion (Order AD 255 294 from OTS, Dept. of Commerce, $2.75) and a bibliography of its unclassified reports, Numbers 5000 and 5500, (order PB 171 907 from OTS, Dept. of Commerce, $1.25) have been prepared by the U.S. Naval Research Laboratory and issued through the Dept. of Commerce, as indicated in parentheses.



He designed a new interchange for radio traffic

This AMF engineer, part of an AMF-U.S. Army team, solved the problem of traffic delays and personal danger in manual re-connection of jumpers when interchanging R.F. transmitters and antennas.

His solution is a push-button-operated, coaxial crossbar switching system, using vacuum switches for circuit selection. A typical system consists of 4 transmitter inputs, 7 antenna outputs plus a dummy load, in a 4 x 8 matrix that can be mounted in a 19" rack. It can be controlled locally or remotely over any type of communication network having a bandwidth of at least 200 cycles.

AMF's coaxial crossbar switching system provides 100% flexibility in circuit path selection and accommodates power levels as high as 500,000 watts and frequencies up to 30 megacycles. It allows 100% utilization of all transmitting equipment. Stubs are automatically eliminated.

To insure fail-safe operation, power is required for the vacuum switches *only* during change of condition. Selection rate: 1 per second. Operating transmitters are safety-interlocked to insure a load. There are no hazards from open wires or inadvertent application of power to dead-lined antennas.

Single Command Concept

AMF's imagination and skills are organized in a *single operational unit* offering a wide range of engineering and production capabilities. Its purpose: to accept assignments at any stage from concept through development, production, and service training...and to complete them faster...in

- *Ground Support Equipment*
- *Weapon Systems*
- *Undersea Warfare*
- *Radar*
- *Automatic Handling & Processing*
- *Range Instrumentation*
- *Space Environment Equipment*
- *Nuclear Research & Development*

GOVERNMENT PRODUCTS GROUP, AMF Building, 261 Madison Avenue, New York 16, N. Y.

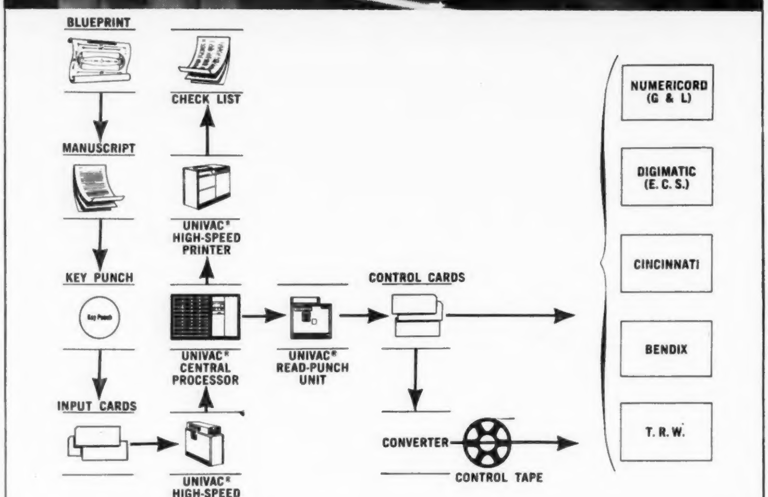
AMF

AMERICAN MACHINE & FOUNDRY COMPANY

Rocket Case on the Spindle

This unique filament-winding machine will automatically manufacture wound-fiberglass rocket-engine cases and missile-fuel tanks for advanced ballistic missiles. The machine, under development by Rohr Aircraft Corp., is controlled by a Thompson Ramo Wooldridge all-transistorized numerical control system (background, near operator).

Rohr has also just finished the first phase of a major development program with Remington Rand Univac that, for the first time, makes possible automatic part programming for different machine tool control systems using a single numerical-control programming system and a medium-scale general-purpose digital computer. The diagram below shows the processing of engineering information in the Rand Univac-Rohr program. The program will permit automatic part programming for the following numerical controls: Cincinnati, Numericord, ECS, Bendix, and Thompson Ramo Wooldridge. It has been proved in use on nine different numerically controlled machine tools in Rohr's Chula Vista plant.



General Pokrovskiy Speculates on Russian Space Flights

USSR General G. I. Pokrovskiy, writing in *Vestnik Vozdushnogo Flota* (Air Force Herald), reviews problems of space flight. Some of his observations are given in the Sept. 13 edition of "Soviet-Bloc Research in Geophysics, Astronomy, and Space," which is available from OTS, Dept. of Commerce, for $16 a year.

General Pokrovskiy says the most complex problem of space flight is the protection of cosmonauts from injury by streams of high-energy particles and short-wave radiation . . . To afford protection equivalent to that offered by the earth's atmosphere would require, he says, a spaceship to weigh 100 tons. He considers this impossible with the present capabilities of rocket vehicles, and so concludes that manned space vehicles must travel only in those areas of space which are relatively safe. This requires the mapping of such zones and corridors,

which vary from year to year, depending on solar activity.

Manned flight, he says, will first be limited to the area below the belt of high-energy particles. The height of the apogee should not exceed 500 to 600 km and the perigee should be no less than 140 to 150 km, an exception being the area over Australia, where the apogee may be as great as 1000 to 1500 km. Thereafter, flights might be made through a corridor along the earth's axis, by-passing the belt of high-energy particles. The third phase of manned flight, he says, will carry a vehicle out seven earth-radii.

General Pokrovskiy also believes that landing a manned spaceship on the surface of any celestial body (except small asteroids) is presently impossible because the trip back to the earth would require a greater supply of fuel than the ship could carry. Landings on planets with belts of high-energy particles will have to be made, he says, through the polar corridors; this probably includes any planet whose diameter is over 6000 km; smaller planets should not have a magnetic field.

Pokrovskiy concludes by stating that this is the period of the "quiet sun" and is therefore favorable for space flights. (Abstract: "Manned Space Flight," by Major General G. I. Pokrovskiy; Moscow, *Vestnik Vozdushnogo Flota,* No. 4, 1961, pp. 59–62.)

A recently published article in the Soviet air force journal reviews generally known information on space flight, but it includes two interesting diagrams. The first, annotated, shows the trajectory for a flight around Venus and Mars with subsequent return to the earth. The second shows the trajectory for a flight around Venus and Mars in one ellipse, rather than in the three ellipses shown in the first. The single-ellipse flight would require 365 days. The most favorable arrangement of the planets for such a flight will occur in 1971. (Abstract: "To the Expanses of the Universe," by V. V. Dobronravov; Moscow, *Vestnik Vozdushnogo Flota,* No. 6, 1961, pp. 8–12.)

Dogs Still Important in Russian Space Experiments

Dogs will continue to play an important role in future space flights, according to Russian Academician V. V. Parin, writing in a recent issue of the Moscow periodical *Znaniye* devoted to several articles on space medicine. (Order 61-31585 from OTS, Dept. of Commerce, Washington 25, D.C., $1.00.)

Space Guidance

(CONTINUED FROM PAGE 27)

Celestial references are preferable for steady-state condition. The sun requires a minimum of logic for identification, and will generally be used to align two axes of the spacecraft. In the vicinity of the earth, and possibly for trajectories toward the sun, the earth may provide the needed second reference. Additional celestial references may be required in the future for determining approach- or terminal-guidance maneuvers in the vicinity of the destination planet for planetary orbits or landings. For trajectories away from the sun, such as those to Mars or Jupiter, the earth becomes a poor third-axis reference. Its luminosity is low, because it is seen as a crescent, and it is difficult to track, because, during part of all trajectories away from the sun, the sun falls in the field of view of an earth sensor at intensities brighter by approximately 12 orders of magnitude. For trajectories away from the sun, some other celestial object is preferable, such as the star Canopus, which is approximately 90 deg away from the sun line.

The configuration and orientation of a space vehicle vary greatly as a function of the mission. Many satellites having three-axis control are oriented with the major axis directed toward the center of the earth and with solar panels having one degree of freedom relative to the spacecraft directed toward the sun. A satellite containing an astronomical telescope might have its major axis directed toward the planet or star being investigated. Lunar and planetary spacecraft under design have the major axis pointed at the sun, with the earth as the reference for the remaining degree of freedom.

Much has been said in the literature about satellite attitude-control systems. The distinguishing feature of attitude control of lunar and planetary spacecraft is that the major external source of torque disturbance comes from solar-radiation-pressure unbalance during cruising flight. The amount of time spent in making maneuvers or in initial acquisition is less than 1% of the total flight duration. Thus the control system must supply a relatively constant, low-level, unidirectional torque during the entire flight. On a typical spacecraft having a large directional antenna not symmetrically located with respect to the sun, this torque would be on the order of 5×10^{-6} ft-lb.

An apparently attractive system to counteract the solar-radiation torque deploys a paddle of equal area on the opposite side of the spacecraft. Since the sun–spacecraft–earth angle is continuously changing during the flight, the balancing paddle would also have to be controlled. A small momentum-exchange device could be used for short-time control. In practice, this system proves to be unwieldy, because of the usual configuration and location of solar panels and scientific instrumentation. Also, because of initial acquisition requirements, the over-all weight of this combined system is slightly greater than an efficient one based on mass expulsion. Control by radiation-pressure balance alone does not appear suitable because of its low torque or acceleration capability, which results in a long time constant for the system.

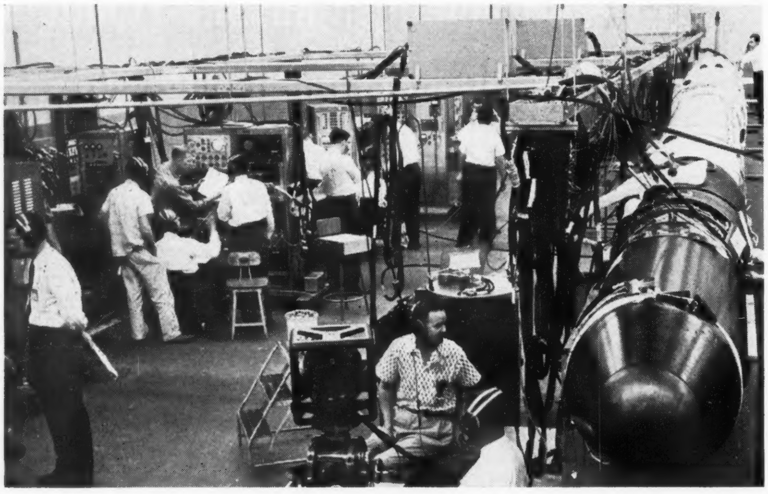
Optimum System for Satellites

The comparison of momentum exchange and mass expulsion on the basis of specific angular momentum (specific impulse) shows a clear preference for mass expulsion to oppose unidirectional torques. Most attitude-control studies for satellites show that an optimum system should contain a momentum-exchange device, such as a reaction sphere, reaction wheels, or torqued gyros which are periodically reset by mass-expulsion jets.

For lunar and planetary flight, however, mass expulsion alone appears more efficient when the amount of momentum-conservative maneuver is small compared to the unidirectional torque requirements for counteracting solar-radiation pressure. The graph on page 26 shows the results of a recent trade-off study comparing two methods of attitude control on a specific-momentum basis. The study showed that a mass-expulsion system using cold nitrogen had a 10:1 weight advantage over a momentum-interchange system using a spherical reaction torque at the level of momentum required for a planetary mission.

After the magnitude and direction of the midcourse or terminal maneuver have been determined, the spacecraft guidance system required to carry out the maneuver is relatively simple compared to that required for injection. The reason for this simplicity is that the velocity increment necessary for a maneuver is on the order of 100 fps compared to the 25,000-fps injection velocity. Thus the combined effects of angular and velocity errors can be many times larger to produce the same target error.

The midcourse- and terminal-guidance systems which have been developed for lunar and planetary spacecraft to date use relatively simple components and techniques. Sensors for autopilots or commanded turns employ floated gyros in a strap-down mode. A body-fixed accelerometer



Scout on the Checkout Line

Chance Vought engineers perform an over-all systems check on NASA's Scout space vehicle. NASA has now designated Chance Vought prime vehicle contractor for Scout and assigned it initial assembly and checkout tasks previously made at NASA-Langley. This shift, which took place with Scout No. 5 in the eight-vehicle program, will cut launch-preparation time.

In Mercury Control Center room at Cape Canaveral, designed under supervision of Bell Telephone Laboratories, NASA flight controllers make all vital decisions concerning a Mercury mission. Large map displays equipment status at tracking and communications sites, preferred recovery areas, the position of the capsule and its "immediate impact point."

Bell System manages building of global communications network for Mercury spacecraft

On September 13, National Aeronautics and Space Administration first achieved the orbital flight of an unmanned Mercury spacecraft, using a new world-wide communications and tracking network.

Soon, will come manned orbital flight.

The Bell System has played a large role in the development of this scientific project.

Western Electric headed an industrial team on which Bell Telephone Laboratories also played an important part in building the world-wide network of tracking and monitoring stations.

This 60,000-mile communications route, the bulk of which is teletypewriter and telephone circuits, ties together 17 tracking and instrumentation sites with the Goddard Space Flight Center in Greenbelt, Md., and the Cape Canaveral Mercury Control Center.

As a Mercury capsule orbits over the area covered by each site, the far-reaching communications network immediately begins feeding information received from the capsule with clockwork precision. So fast and efficient is this communications system, it takes only seconds for data to start flowing from any site through Goddard to Canaveral!

The Bell System is proud to have contributed its creativity and resources to this vital project and to the further advancement of global communications.

BELL TELEPHONE SYSTEM

AMERICAN TEL. & TEL. CO. / WESTERN ELECTRIC CO. / BELL TELEPHONE LABORATORIES / 21 OPERATING COMPANIES

without the complexity of resolving attitude variations is usually satisfactory for all but the most stringent missions. For slightly higher accuracy, integrators may be placed in the position loop; gimbal-angle or jet-vane-angle feedback may be added; or side components of acceleration could be measured by additional accelerometers. To date, it has not been found necessary to go to the complexity of a full inertial platform to meet the requirements of space midcourse and terminal guidance.

The orientation of the thrust vector can be controlled by several different techniques, depending on the level of thrust. In general, the same cold-gas jets used during cruising flight are not suitable, since the torques due to center-of-gravity offsets from the rocket thrust line are on the order of 10^6 times larger than solar-radiation unbalance. For thrust levels below approximately 500 lb, jet vanes in the rocket exhaust appear to be optimum. For higher thrust levels, such as might be required for the lunar soft landing, gimballed rocket motors, multiple throttleable motors, or a fixed retromotor and gimballed vernier motors would be more efficient. The configuration of the spacecraft and the thrust-vectoring system are extremely dependent on the requirements of the mission, and trade-off studies are required to select the most suitable approach.

LUNAR-LANDING GUIDANCE

By K. S. Watkins

The magnitude of the arrival velocity of the spacecraft in the vicinity of the moon for typical lunar trajectories is of the order of 2600 meters per sec, or about 5800 mph. The spacecraft must be oriented and braked from this velocity to arrive at the lunar surface with essentially zero velocity and to land vertically. More practically, however, landing velocity will not be zero but will be limited to a few meters per second in both vertical and lateral directions, as indicated in the sketch on page 26. The spacecraft may incorporate a landing structure to minimize shock and the chance of its toppling during landing. With proper attention to landing dynamics and structure, the touchdown shock can be limited to 25 earth g or less. It is interesting to note that a parachutist landing on earth will normally impact at about 5 meters per sec and suffer a shock of 4 or 5 g.

There are several functional requirements to be met by the flight-control system. First, it must incorporate a propulsion system, appropriately scaled and capable of being modulated in thrust for control of descent velocity. Second, there must be on board the spacecraft an accurate means of determining position and velocity relative to the lunar surface, in order to provide the signals for attitude and velocity control during descent. Finally, the efficiency of the descent must be kept as high as possible to minimize propellant requirements.

Under the best conditions, a lunar soft landing requires a high propellant mass fraction. Using a propellant with a nominal specific impulse of 300 sec, removal of the total 2600 meters per sec will require that about 60% of the total pre-retro weight of the spacecraft be allotted to propellant. Only a rigorous optimization of the descent system will ensure that no unnecessary penalties are being taken in total propellant utilization.

When the spacecraft arrives in the vicinity of the moon, earth-based tracking will yield knowledge of its velocity magnitude to a few meters per second and its velocity direction to a fraction of a degree. However, spacecraft position relative to the lunar surface may be uncertain by 10 km or more.

During the earth to moon transit, attitude reference for the spacecraft can be provided by optical sensors locked to the sun and earth (or star) directions. A set of orthogonally mounted gyros may provide rate control about the three spacecraft axes and the means for short-term precision maneuvering of the spacecraft for thrust-axis alignment. The latter can be accomplished by gyro (and, hence, spacecraft) torquing to the computed direction by earth-based radio command. Implicit in the spacecraft mechanization is a system of reaction torquing for the continuous maintenance of spacecraft attitude.

When the spacecraft is still 10 to 20 min away from lunar impact (corresponding to an altitude of about 1500 km) and still possesses its transfer attitude references and orientation, a maneuver can be initiated by radio command to align the spacecraft's thrust axis opposite to its velocity vector, preparatory to braking the spacecraft for landing. Once descent has been initiated, the spacecraft must continue on its own devices, without further dependence on celestial references or aid from ground tracking or command. Tracking data are not only inadequate for the accuracies required in determination of altitude and vertical velocity, but also the time delay in transmission of guidance data between earth and spacecraft would be prohibitive.

Measurements of position and velocity relative to the lunar surface must be made. For initial ignition of the

retro system, a simple measurement of altitude may suffice. Such a measurement may be made either by means of an optical horizon scanner or by using pulse-radar techniques. The choice depends on the altitude of ignition and the required accuracy, and on how the device is otherwise to be employed during descent.

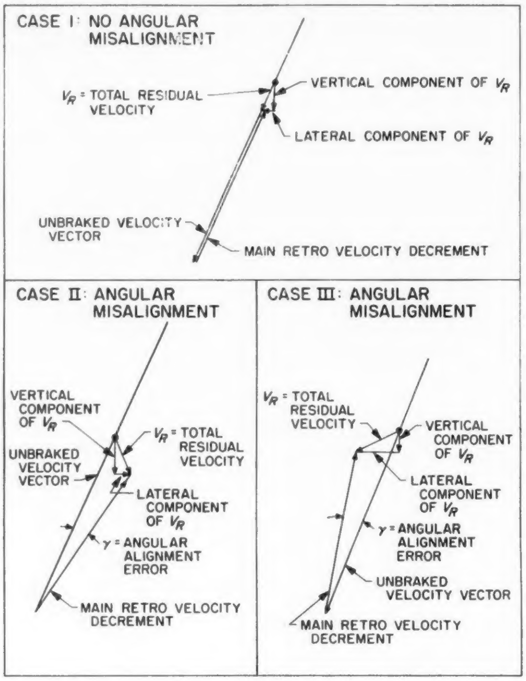
Electrical-power requirements and total weight become restrictive for radar equipment at ranges of 100 mi. or more. Primary restrictions in the use of optics lie in the dependence on lunar-lighting conditions and in the possibility that lunar-surface irregularities could portray a "false horizon" to the optics at the lower altitudes. Under suitable conditions, either system is capable of indicating ignition altitude to 2% or better.

At some point in the descent, measurement of altitude and both vertical and horizontal components of velocity must be initiated, and continued essentially to touchdown. A precision radar altimeter appears to be the best means for the continuous and precise measurement of altitude. Velocity can be determined by means of a multi-beam Doppler-radar system or by using optical V/H drift-meter techniques. In principle, either a Doppler or an optical system must consist of at least three active beams suitably distributed about the roll axis of the spacecraft and "squinting" out at equal radiating or viewing angles from the roll axis, as shown in the diagram on page 27. Thus the signal resolved from each beam (for either system) will be proportional to the relative velocity of the spacecraft with respect to the moon along the beam direction. By resolution of the velocity information of each beam into components along the pitch, yaw, and roll axes of the spacecraft, error signals for control of both thrust and spacecraft attitude can be derived. A disadvantage of the optical system is its dependence on lighting conditions.

Soft-Landing Descent

For maximum efficiency and simplicity, it would appear that the total velocity decrement of 2600 meters per sec required for soft landing should be achieved in a single short impulse, at a level of thrust which is limited only by the load capability of the spacecraft, and with a simple propulsion system, such as a solid rocket. In practice, however, uncertainties in measured position and velocity, in angular alignment of the thrust axis, and in burning characteristics of the propulsion system (as a function of temperature, mixture ratio, chemical constituency, propellant loading, burning time, etc.) would result in altitude

Effect of Angular Misalignment in Velocity Error Generation



and velocity dispersions far in excess of those admissible as soft-landing conditions. It is thus evident that some form of velocity or thrust-level control must be employed in the soft-landing descent. It is also apparent in the mechanization that the descent time cannot be less than the time necessary to generate and execute the necessary guidance commands. Furthermore, engine throttleability requirements should not become excessive.

Within these requirements, two modes of descent present themselves. One utilizes a single engine modulated in thrust. The modulation may be partial, say to 90% of full thrust, or total, to zero, in which case the engine is started several times. Note that difficulties in sensing through the flame may require that the engine be turned off occasionally.

The second mode of descent employs two separate engine systems—one to provide a fixed increment of thrust at high level, for rapid removal of the bulk of the energy, and a lower-level, throttleable system for reducing the remainder of the velocity.

The main engine should be sized to remove a major fraction of the spacecraft velocity with a short, fixed-direction impulse at near-constant thrust. Upon termination of this thrust, the vernier system will take over to remove the nominal residual velocity, plus whatever velocity dispersions have accumulated. We assume that the main-engine burning is guided without external sensing, in the event that the exhaust is opaque. We further assume that the vernier system exhaust is transparent, and that full guidance based on external sensing will occur during the vernier period.

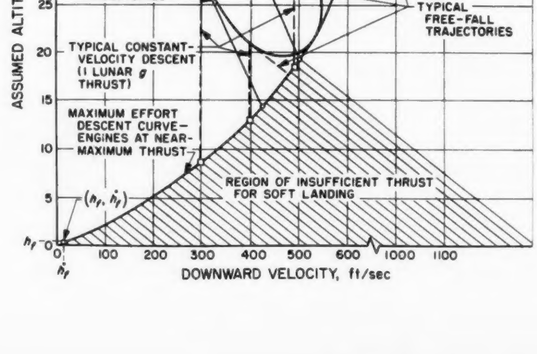
For maximum descent efficiency, the main engine must be characterized by a high thrust-to-weight ratio, a high specific impulse, and a high total impulse. On a lower level, the vernier system should be similarly endowed; but, in addition, it must also be capable of being modulated in thrust (from T_{max} to T_{min}) over a moderate ratio. The minimum thrust of the vernier system should be less than the lunar weight of the spacecraft near propellant depletion to permit the spacecraft to "fall" toward the moon while still under minimum thrust for attitude control. The maximum thrust of the vernier system should be as high as practical to maximize the braking rate of the spacecraft during the maximum-effort phase of the terminal descent. The graph on page 27 shows the maximum- and minimum-thrust vernier trajectories.

This graph also shows the over-all descent profile for the two-level retro system. This consists of the fixed-impulse, fixed-direction main retro trajectory, with associated dispersions due to initial conditions of descent and engine-burning characteristics. The profile also shows the guided vernier descent trajectory to touchdown.

The initial velocity dispersion, δV_a, at the main-engine ignition is of the order of a few meters per second, as derived from earth-based tracking; this results in a contribution to the altitude uncertainty at main-engine burnout. The initial attitude uncertainty, δh_a, is directly attributable to the accuracy of an altitude-marking device aboard the spacecraft. A primary effect of δh_a is an increase in velocity uncertainty at burnout.

The third uncertainty which exists at the initiation of descent is in the vehicle thrust-axis alignment, which is

Typical Vernier Descent Trajectories



Gas Deflectors for Test Structures

Bonded silicon carbide brick and semi-circular segments offer great flexibility in the construction of special deflectors used during rocket and jet engine tests. This unique material resists the tremendous heat shock, flame erosion and ultra-high temperatures exhaust gases generate during firing.

Rocket Nozzles and Liners

NIAFRAX® nozzles and liners meet the severe conditions encountered in uncooled rocket motors. They stand up to extreme temperatures, heat shock and erosion *for the full burning time.* NIAFRAX parts usually good for repeated firings. Can be produced in intricate shapes; close tolerances.

For High Temperature Refractories for Jet and Rocket Development

...count on

CARBORUNDUM®

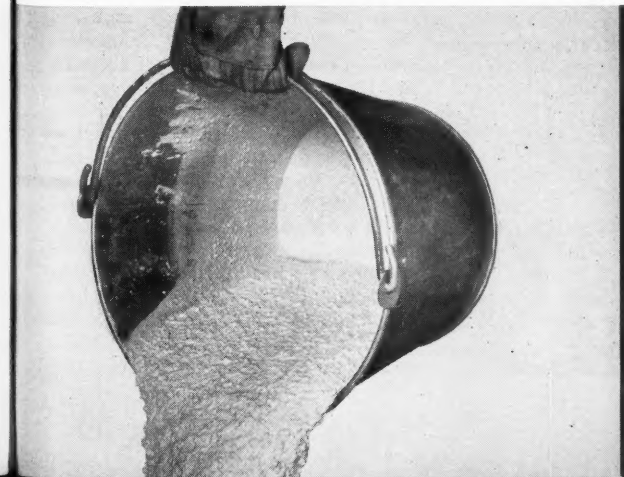
Dept.K-111,Refractories Division, Perth Amboy, N. J.

High Temperature Castable Cements

ALFRAX® BI castable aluminum oxide cements offer about the most effective materials for insulating at temperatures up to 3100°F—especially at the higher end of the range. They show little or no shrinkage and are unaffected by atmospheres, combustion gases, etc. Simply mix with water and pour.

Fused Alumina "Bubbles" for Potting Work

These "bubbles" provide the high dielectric strength of electrically fused alumina. They offer light weight coupled with the ability to resist temperatures far above those usually attained. Their free-flowing characteristic gives assurance of easy filling and close packing into all areas.



fixed inertially for the period of main-engine burn. Shown at the top of page 68 are some typical alignment geometries illustrating that an initial alignment uncertainty of as little as 1 deg can result in many degrees of uncertainty in the direction of the residual velocity vector at burnout and as much as 100 fps in magnitude. An efficient descent program requires that all such dispersions be minimized.

Also shown on page 68 is a larger-scale profile of the vernier-guided descent trajectory. Vehicle thrust and attitude are controlled during this phase, requiring the previously indicated continuous measurement of altitude and both components of velocity.

At burnout of the main engine (after which it may be jettisoned, if practical, for fuel conservation), the resultant velocity of the spacecraft will, in general, have both lateral and vertical components. However, as a consequence of the velocity dispersions, shown on this last graph, the velocity vector and the vehicle thrust axis are no longer necessarily aligned.

The descent guidance consists of two modes. For maximum efficiency, we shall assume that first there occurs a period of descent from point of main-engine burnout under minimum vernier thrust to a point (h_i, $\dot{h}_i$) on the h–$\dot{h}$ profile at which maximum effort is required of the vernier-engine system to accomplish the remainder of the descent as programmed. Examples of the minimum-thrust trajectories appear on the graph on page 68. For efficiency, a low minimum-thrust level is desirable. Lateral guidance is initiated during the minimum-thrust phase and continued for the approximate remainder of the descent. The pitch and yaw components of measured velocity are fed to the corresponding gyros for control of the vehicle attitude and for nulling of the lateral velocity. This is accomplished by "tipping" the spacecraft thrust axis to achieve the necessary velocity decrements in the pitch and yaw directions. Thus, when no lateral velocity component exists, the spacecraft thrust axis will be vertically aligned, lateral velocity will be zero within tolerable limits, and only the vertical component of velocity will remain.

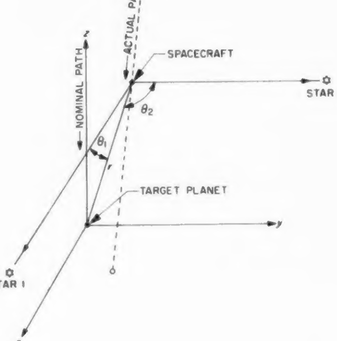
When the point (h_i, $\dot{h}_i$) for maximum effort has been reached, as indicated from sensed velocity and altitude, the second mode begins, calling for full vernier thrust, and, at the same time, closes the guidance loop for control of thrust, as a function of measured altitude and the vertical (roll-axis) component of velocity.

The spacecraft will descend in this mode until a specified point (h_f, $\dot{h}_f$) is reached just off of the lunar surface, from which the spacecraft will descend either in "free fall" or at constant velocity (1-lunar-g thrust), to the lunar surface. At the point, h_f, $\dot{h}_f$, at a proportionate expenditure in fuel, a "hovering" mode could be introduced for final landing-site selection via real-time TV to earth. Lateral excursions of the spacecraft are readily accomplished directly with the lateral-guidance mode described.

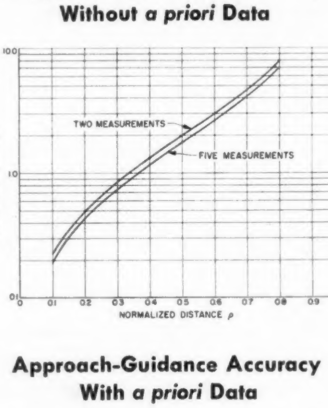
The "target" values of h_f and $\dot{h}_f$ will depend upon the accuracy of the h, $\dot{h}$ measurements and, perhaps, upon other landing restrictions as well. Whatever the nature of this final descent to touchdown, it is important to minimize rotational rates of the spacecraft (which might be caused by shutdown transients of the vernier engines) so as not to impair the stability at landing.

Once on the surface, electrical power would be removed from the guidance equipment, and the spacecraft would be ready to initiate its post-landing operating sequence—beginning, it is hoped, with a report to earth of physical survival.

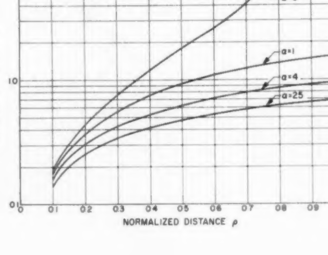
Approach-Guidance Measurements



Approach-Guidance Accuracy Without *a priori* Data



Approach-Guidance Accuracy With *a priori* Data



PLANETARY-APPROACH GUIDANCE

By C. R. Gates

The table on page 24 shows that the miss distance at Mars or Venus resulting from earth-based midcourse guidance is serveral thousand kilometers. For many missions, such as landing in a given area on the surface or passing by the planet at a controlled distance, such a target dispersion will be unacceptable. Since the capabilities for guidance from the earth are exhausted by earth-based midcourse guidance, further guidance must be contained in the vehicle. We shall use the term approach guidance to describe guidance performed in the region from, say, a hundred thousand to several million kilometers from the planet, and having as its purpose reducing the miss distance from that remaining after midcourse guidance to a value acceptable for the mission. Guidance still closer to the planet is usually called terminal guidance and will not be discussed here.

In the paragraphs which follow, all quantities will be referred to the target planet. Note that a ballistic approach to the planet must be hyperbolic. Also, in the region of approach guidance, the speed of the spacecraft will be almost constant, and its path will be very nearly a straight line along the incoming asymptote of the hyperbola.

We first observe that fuel economy demands that the guidance be performed as far from the planet as possible. For the assumption of straight-line motion, the effect of a lateral velocity maneuver is $d = r\Delta V/v_h$, where ΔV is the magnitude of the maneuver, r is the distance from the planet at which the maneuver is executed, v_h is the speed of the spacecraft, and d is the effect, at the target, of the maneuver. (The effects of target focusing are ignored here.)

Thus, if we have to correct a miss of 5000 km, the approach speed is 5 km per sec (a typical value), and we wish to perform the correction at 10^6 km, a maneuver of $\Delta V = 25$ meters per sec is needed. If we wish to make the maneuver at $r = 10^5$ km, we shall require 250 meters per sec. Note that, for a rocket propellant having a specific impulse of 300 sec, 1% of the spacecraft weight in fuel yields a maneuver of 30 meters per sec.

We next ask what measurements can be made from the spacecraft to compute the required maneuvers. Clearly, some measurements will have to be made with respect to the planet. Radar measurements from 10^6 km require excessive power, but optical measurements seem thoroughly feasible. At $r = 10^6$ km, we should have no difficulty in identifying the planet. Since optical measurements generally yield angular information, we shall assume, as shown in the diagram on page 70, that the angles, as seen from the spacecraft, between the planet and suitably selected stars are measured. The diagram shows the use of two stars in the direction of the x and y axes. The nominal path of the spacecraft is along the z axis.

The measurements indicated in the diagram are adequate to determine miss distance at the planet, but they do not determine the distance, r, of the spacecraft from the planet. The quantity, r, will be needed to determine the time when observations are to be taken and maneuvers made; r can be found either by (1) measuring, in the spacecraft, the angular diameter of the planet, (2) making radar measurements from the earth of range to the spacecraft, or (3) a combination of one and two.

The two graphs below the one on page 70 show how accurately its angular measurements determine the miss distance. The accuracy has been normalized with respect to the RMS angular error in the observation of the angles and with respect to the greatest distance at which an observation is made. For example, suppose two measurements of the angles θ_1 and θ_2 are made at distances of 10^6 and 5×10^5 km, with an accuracy of 10^{-3} rad. From the upper curve of the middle graph, we read, for $\rho = 0.5$, $D = 2.0$. Multiplying $2.0 \times 10^6 \times 10^{-3}$ yields an accuracy of 2000 km, meaning that we can predict where the spacecraft will go with an RMS accuracy of 2000 km. In the lower curve of this same graph, five measurements are assumed: One at $\rho = 1$, one at the value plotted, and the remaining three equally spaced—i.e., the value plotted for $\rho = 0.6$ ($D = 2.6$) assumes that measurements are made at $\rho = 0.6$, 0.7, 0.8, 0.9, and 1.0.

The middle graph assumes that no *a priori* data are used. However, some information will be available concerning the trajectory; in particular, we shall know something (statistically) about the direction from which the spacecraft is coming. The bottom graph on page 70 shows the effect of such *a priori* data. The quantity $\alpha = (\sigma_s/\sigma_a)^2$, where σ_s is the RMS error in θ_1 and θ_2, and σ_a is the RMS error

in our *a priori* knowledge of the direction cosines of the incoming asymptote. As one would expect, large α, corresponding to more precise *a priori* information, yields greater accuracy.

To construct a practical example, suppose that the sensor accuracy is 10^{-4} rad RMS, $\alpha = 4$, and five measurements are made from $r = 2 \times 10^6$ km to $r = 250$ km. From the bottom graph, for $\rho = 0.125$, we read $D = 0.2$. Thus the accuracy of our knowledge of the trajectory is 40 km RMS.

Further analyses would be needed to determine the optimum distance at which to make maneuvers, the optimum number of maneuvers, the effects of errors in executing maneuvers, etc. In general, it will be found effective to perform more than one maneuver. ♦♦

Terrestrial Guidance

(CONTINUED FROM PAGE 35)

inertial methods therefore is of concern to the engineer concerned with any form of navigation. Emphasis on the self-sufficient or universal character of the method does *not* imply that it will necessarily dominate or replace other methods. As has always been so with navigation, different methods are not so much competitive as complementary.

The inertial method depends on gyros to establish a directional frame of reference, accelerometers stabilized by or referenced to the gyros, and integrators and computers for reading out velocity and position in a selected coordinate system. Gravitational acceleration, which accelerometers are incapable of distinguishing from inertial acceleration, is taken into account as present in different ways, depending on application.

For cruise vehicles it is often convenient to keep the platform's stable element (gimballed gyro and accelerometer assembly) level; this is accomplished by feeding back singly-integrated acceleration signals as variable gyro-control torques. No explicit calculation of gravity components is involved, although scale factors in the feedback channels are selected to give the quasi-pendulous stable element the period $T = 2\pi(R/g)^{1/2}$ where R is earth radius and g is acceleration of gravity at the radius ("Schuler tuning"). Some forms of SINS systems exemplify this class.

For ballistic-vehicle guidance it is more convenient to preserve the launching-point orientation of the stable element (by application of *constant* earth-rate compensation torques), rather than to maintain it locally level. Assuming a certain set of axes (x, y, z) earth-fixed at the launching point, stable-element axes (x', y', z') remain parallel thereto during the guidance phase. Gravity is computed as a function of displacement from the origin in three dimensions and is algebraically added at a suitable point in the system.

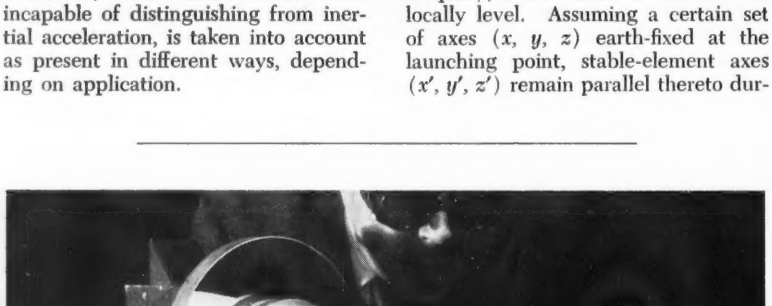
With increasing refinement and improvements in the inertial components and computer, it is predicted that the two modifications will merge. That is to say, the practical need for keeping a platform stable element in a definite orientation relative to the earth will disappear. As a further step of emancipation, even the stable element may be eliminated in some applications—gyros and accelerometers being fastened to the airframe, and the computer, taking gyro-measured incremental angles as input, keeping track of maneuvers (and of time) and resolving sensed accelerations into horizontal and vertical components by computation. The instrumentation problems in such systems—subject of study in several current programs—are formidable. To illustrate: If the gyro's angular-momentum vector is to be closely constrained to the airframe, a linear torquer of very wide range is required. If the gyro rotor is "free," an unlimited-range precision angle pickoff is required. Computer speed and resolution requirements are high in both cases.

The accuracy obtainable in inertial guidance is limited ultimately by two factors. The first is knowledge of the gravitational field of the earth or other celestial body capable of influencing the movements of the vehicle. Obtaining such knowledge is a problem of geodesy and astronomy. Practically speaking, it may be considered as solved for cruise-type navigational purposes, although not so for some long-range ballistic-vehicle operations. The second limiting factor is the perfection of the instrumentation, most especially the gyros and accelerometers.

The accuracy presently obtainable with inertial systems is usually classified information. However, extensive use as an alternative to other kinds of accurate navigational systems indicates a high level of performance. For many applications, accuracy of existing equipment is sufficient, although system size, weight, power requirements, complexity, and cost leave considerable room for improvement. For other applications, attainment of a level of accuracy beyond which further improvement would not be worthwhile is still a distant goal. This holds for the gyros for submarine navigation and accelerometers and gyros for some kinds of ballistic-vehicle guidance. Truly adequate reliability likewise is still a distant goal.

Inertial-component development is in a state of transition from the classical machine-design approach of a dec-

---



Sperry Light Beam Modulator

Sperry Gyroscope light beam modulator, designed to boost guidance and control system performance. By using pencil-thin light beams to replace microwave radar beams, the device is expected to help space vehicles rendezvous accurately with satellites or space stations. The modulator is expected to find its greatest application in conjunction with lasers.

ade ago. In particular, gyros based on mechanical spin bearings and gimbals, which dominated the field in the years immediately after the war, are subject to formidable competition. Instruments produced by one manufacturer, utilizing gas-lubricated rotor-spin bearings, are in operational use, and other manufacturers have announced their intention to replace ball bearings by that type, which is characterized by extreme rigidity and virtual absence of vibration.

Furthermore, all kinds of gimballed gyros are encountering competition from the new so-called "free-rotor" type, in which the rotor is given all three degrees of freedom by some sort of spherical bearing. So far, only the gas-supported free rotor has found operational use. Free-rotor gyros based on electrostatic and magnetic support *in vacuo* are under active development, with the object of attaining accuracy beyond any with a material bearing. In all free-rotor gyros, a requirement exists for nearly perfect geometry, for high stability of materials, and for critical surface conditions. In magnetically supported gyros, the electrical and magnetic properties of the rotor material in bulk are likewise critical. Solution of these problems takes gyro design more and more into the province of solid-state physics and molecular engineering. The most radical approaches, still in an embryonic stage, seek to avoid altogether problems associated with material in bulk and to capitalize on the perfect inertial properties of atomic nuclei. It does not appear that any nuclear instrument so far has passed the preliminary physical examination for the Gyro Club—detection of earth rotation.

In the case of accelerometers, the mechanically complex gyro pendulum is hard-pressed by devices which perform the sensing and integrating function in mechanically simpler ways—such as the inductive type based on use of a conductor-and-magnet tachometric coupling; instruments based on acceleration-sensitive electromechanical or electrical osillators; and force-balance type accelerometers, in which the force-responsive direct current or voltage is digitized to give a pulse rate proportional to acceleration. All such devices involve heavy reliance on constancy and stability of materials and circuit elements at the molecular level.

Digital vs. Analog

The digital has virtually displaced the analog computer for inertial navigation. Among other improvements, the digital computer has made possible considerable simplification of stable platforms and its components, which now no longer must perform analog-computer functions.

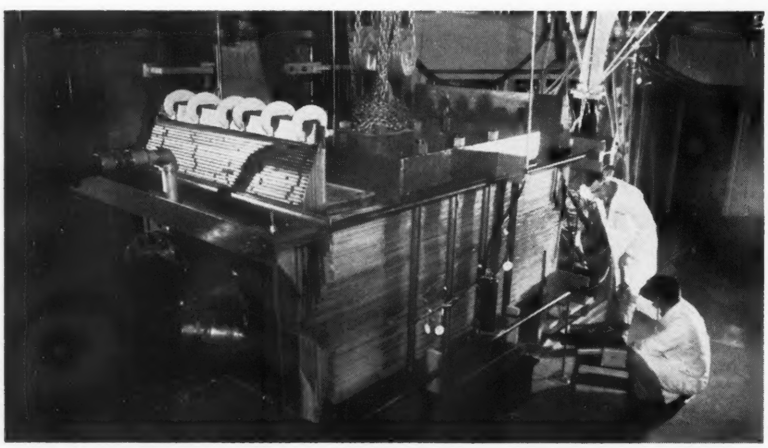
Inertial-navigation systems are in routine operation in many submarines and large ships of the Navy. They are also present in airborne missiles. Practically every known long-range ballistic missile utilizes inertial guidance. In civilian applications, marine and aeronautical, the inertial method must compete with radio methods, some of which, based on ground installations, require a minimum of craft-borne equipment (and a maximum of taxpayer-borne equipment). Reduction in size, power requirements, and cost may result in the introduction of inertial "dead reckoners" to interpolate or extrapolate radio-navigational information.

"Inertsial'nie navigatsionnie sistemi" receive considerable space in the USSR technical literature. The books and papers are mainly of a theoretical, tutorial, and review character. Much respectful attention is given to U.S. developments; little is revealed of the state of the art in the USSR.

Although we are concerned here primarily with apparatus, it must be mentioned that the changing state of the art of analysis parallels that of apparatus. Inertial-guidance theory is handled by methods which are much more refined and expeditious than those of 10 years ago, and which in some important cases result in simpler or more accurate mechanizations.

Optical Methods. Until quasi-perfect gyros come into existence, the opportunity for direct check with the "firmament" via a star tracker, when occasion permits, will remain attractive, especially for applications involving long cruise times. Trackers for mounting directly on the platform stable element—the most desirable arrangement from the point of view of accuracy—must be very compact. In existing designs, the telescope optics, photosensitive device, and altazimuth-angle measuring devices are of comparable size, so that any substantial further miniaturization would require improvements in all these items. Principal developmental activities are along the lines of one-piece catadioptric telescopes with multiple internally-reflected light paths, solid-state photosensitive devices as alternatives to the much-used photomultiplier (1P21), investigation of different spectral regions, especially the infrared (1 to 15 μ), and non-mechanical angle-measuring devices of inductive ("Inductosyn") and electrostatic and optical types Much of this work is directly applicable to extraterrestrial guidance systems.

In terrestrial navigation, for a long time "optical tracker" was essentially synonymous with "star tracker." Even



MHD on the Ground

This large magnetohydrodynamic generator at Avco-Everett Research Laboratory is designed to produce eventually upwards of 500,000 watts of power. It will be used to evaluate engineering problems of MHD power generation. Studies of the design and operation of such generators were reviewed at the recent ARS-Northwestern Univ. MHD Conference (see page 40).

the planets were ruled out because of their complex real and apparent motions (requiring excessive computer information storage capacity) and because they could not always be treated as point sources. The tracker now is being brought into more versatile use, as in scanning the terrestrial horizon to determine the vertical from high-altitude vehicles. Thus the angular field presented to the tracker may range, without discontinuities, from essentially zero to nearly 180 deg. ("Vertical" must be redefined broadly as the line to the center of the orb—earth, sun, or planet—which is governing the movements of the vehicle.)

Radio-Celestial Methods. Microwave systems have been developed for ship-borne use that are capable of reliably tracking the sun and moon. Conflicting requirements must be met. Radiation at the wavelength of maximum energy, about 0.9 cm, is subject to atmospheric obstruction (rain scattering), but a small secondary maximum exists at 1.8 cm. Using radiation of such wavelength, and paraboloids somewhat less than a meter in diameter, RMS errors of the order of 2 or 3 min of arc are reported as typical. Accuracies should improve. The same apparatus can be used to track artificial satellites. Combined "artificial-natural" celestial navigation has some attractive features. Prospects for utilizing natural bodies other than the sun or moon are quite unfavorable.

Methods With Artificial Satellites. Navigation based on use of artificial rather than natural celestial bodies differs significantly from traditional celestial navigation. The bodies move fast, so that in marine applications obtaining a "fix" with the aid of successive observations of a single body is much facilitated. Moreover, they can be made to be more readily detectable than stars and planets, and they can be made to "talk." A negative feature is that navigation based on such bodies is subject to countermeasures and possibly unintentional interference due to accumulation of "space trash" in the terrestrial sub-orbs.

Three ways of utilizing artificial satellites come into consideration, depending on whether range rate, range, or direction is the quantity measured. In general, optimum satellites would be of different type for each mode of use and would be placed in orbits of different radii.

The Transit navigation system, which is intended to be operational in 1962, is based essentially on range-rate measurement. It involves the provision of a set of four close (600-mi.) artificial satellites in polar orbits, expressly designed and operated as an aid to the navigation of surface vessels. Each satellite continuously broadcasts a selected pair of very accurately controlled frequencies (a pair is used to permit compensation for ionosphere-refraction effects). Also, every minute or so it transmits coded information as to the elements of its orbit. This latter information is obtained from ground stations which observe the satellite, compute its orbital elements and any predicted changes therein, and send the information to the satellite for storage and re-broadcasting, such updating being necessary about once a day.

The vessel, assumed to be at one side of the orbit, receives signals for some minutes as the satellite traverses the sky. Detection of the point of zero frequency shift (zero range rate) establishes the vessel on a line of position normal to a known point in the satellite orbital plane. Analysis of the function of the rate of change of the received Doppler frequency as a function of time, during the traverse, yields a fix on the line. A very accurate ship-borne time standard is required.

For precision fixing (to 0.1 mi.) the computational operations are complex,

requiring an elaborate and costly ship-borne digital computer. For obtaining position to the same sort of accuracy as is obtained in ordinary celestial navigation (1 or 2 mi.), the computations are within the scope of equipment which is practical for the merchant marine.

A more remote satellite—of height, say, 2000 mi.—has the advantage of requiring less frequent up-dating, but also becomes less sensitive to the range-rate method. It has been proposed in such a case to measure range, with the aid of a ship-borne radar and a satellite-borne transponder. A pair of range "sights" gives intersecting circles of position.

Neither of these methods constitutes a complete navigational system, because directional information is not obtained and because data is not continuous. Use in conjunction with a gyrocompass and log or an "interpolative-grade" inertial navigator is presupposed.

A satellite sufficiently remote could have its orbit handled by ephemeris methods, as is done for the moon and sun, circumventing the problem of broadcasting and receiving orbital data. This approach would have to be employed in conjunction with optical or radio direction-measuring methods. It does give directional information and could also be quasi-continuous, given sufficient satellites.

Let us turn now to methods using terrestrial frames of reference.

Radio Methods. The most nearly self-contained kind of system—hence the one of most nearly global application—is one based on Doppler-frequency-shift measurements of microwave radiation directed from the craft and re-radiated from the earth's surface. Such systems have gone into operational use. Accuracy is limited ultimately by noise and by indeterminate topography (or ocean waves) to a fraction of 1% of distance traveled. At present, however, in many cases accuracy is limited by inadequacies of the heading references provided for resolution of the ground-speed information. A heading reference to achieve the full potential accuracy has to be of inertial-navigator quality. In addition, signals can be erratic or lacking in traversing unfavorable terrain, such as the Arctic Ocean, so that some form of interpolator must always be provided. Doppler-radar and inertial systems can be combined in various ways for mutual benefit, but considerations of complexity and cost so far have precluded extensive exploitation of joint systems.

Methods based on measurement of travel-time or phase differences between radiation from a plurality of ground-based stations have found extensive use in marine and air navigation. Within a few hundred miles of stations, accuracy can be very high, and craft-borne equipment is relatively simple. The chief limitation is the high cost of establishing and maintaining the stations in remote regions. This has resulted in confining installations to areas of relatively dense traffic. Navigators of the Arctic and Indian Oceans, for example, will probably have to rely on self-contained equipment for a long time to come.

Radio-radar methods of guiding the launching phase of rockets are important, but are not considered here, inasmuch as their principal application is to artificial satellites and other extraterrestrial vehicles. For ballistic missiles, non-radiating guidance methods are generally preferred. (Practice in the USSR may differ.)

Acoustical Methods. Acoustical methods, together with inertial, are the only ones of general applicability in the opaque ocean depths. Several of the acoustical methods are the "hydraulic analogs" of radio methods. For example, there exist Doppler-effect ground-speed meters and hyperbolic schemes analogous to Loran. All are limited in accuracy by uncertainties in the acoustic-wave propagation properties (speed and direction) in the local medium and also by rather high noise levels. To consider only the matter of speed, the magnitude of the temperature coefficients in the following expression for speed in salt water shows what one is up against in achieving high accuracy: Speed (cm/sec^2) $= 140{,}000 + 421\,t - 3.7\,t^2 + 110\,S + 0.018\,d$, where t is in degrees C, S is salinity in parts per 1000, and d is depth in cm.

Increasing knowledge of acoustic-wave propagation as a result of oceanographic research may yield significant improvement in accuracy and range of acoustic navigation. The state of the art of acoustical methods is kept confidential because of its significance to submarine warfare.

As a means of object detection, sonar mapping, and signaling—branches of technology with which we are not concerned here—acoustic methods appear to have a rich future. As a means of *navigation*, as defined at the beginning of this article, acoustic methods must compete with the inertial method for submarine use and with inertial and radio methods for surface use, both of which are potentially more accurate. Acoustic depth-finding has an indefinite future. Short-range sonar navigation of small submarines also may be a promising field.

Miscellaneous. Navigational methods based on air- and water-speed measurements, and on the earth's mag-

netic field for direction, have long since reached a point where further refinement of instrumentation will not increase their (poor) accuracy. However, a basic simplicity and reliability insures them an indefinitely long future.

Measurement of distance along the earth's radius (altitude or height) and rate of change thereof remains in a state far from satisfactory. Only the inertial method can make such determinations accurately, and the unbounded nature of the error function restricts such method to guidance operations which last but a few minutes, as with rockets. At least for aircraft, all other known methods are limited in accuracy, and seriously so, by the quality of the measured data rather than by instrumentation.

On the University Level

Lastly, as "miscellaneous" items, we note with gratification the increasing attention being given to navigational science and engineering in university curricula, and we note with distress the lag in adoption of the metric system in navigational theory and practice. The English system is an unnecessary impediment.

The author wishes to acknowledge the professional courtesy of members of the following organizations, who replied to requests for state-of-the-art information: Collins Radio Co. (Research Dept.), GE (Heavy Military Electronics Div.), Sperry Gyroscope Co. (Inventions Research Dept.), U.S. Naval Electronics Laboratory (High Resolution Sonar Br.). The author remains entirely responsible for all statements of fact and opinion.

Suggested Additional Reading

State of the art of inertial and optical methods is covered in the papers presented at the ARS Guidance, Control, and Navigation Conference, Stanford, Aug. 7-9, 1961. Following are a few references to review-type works in fields not stressed at that Conference.

"American Practical Navigator," USN H.O. Pub. No. 9, Washington, D.C., 1958, obtainable from the Supt. of Documents, Government Printing Office, Washington 25, D.C. (Includes descriptions, primarily from the operational viewpoint, of many electronic marine navigational methods.)

Marner, G. R., "Plotting the Future Course of Marine Celestial Navigation," *Navigation* (Los Angeles), Vol. 7, No. 4, 1961, p. 213. (Radio-celestial, including various uses of artificial satellites.)

Marner, G. R., "Automatic Radio-Celestial Navigation," *Journal of the Institute of Navigation* (London), Vol. 12, Nos. 3 and 4, July-October 1955, p. 249.

Rogoff, M., "Loran Navaids for Long Range Flight," *Aero/Space Engineering*, May 1958, p. 44.

Fried, W. R., "Doppler Radars for Guidance; Design Techniques and Performance." *ARS Journal*, December 1959, p. 957.

Albers, V. M., "Underwater Acoustics Handbook," Penn. State U. Press, 1960. (Generation, propagation, detection, etc.)

"Monthly Index of Russian Accessions," Library of Congress, Washington 25, D.C. (Includes entries for the extensive Russian literature in navigational science and technology.)

♦♦

People in the news

APPOINTMENTS

Donald N. Michael, formerly senior staff member, The Brookings Institution, has been appointed director of research, The Peace Research Institute.

NASA has announced the promotion of **Thomas F. Dixon** from director to deputy associate administrator of the Office of Launch Vehicle Programs and the appointment of **Abe Silverstein** to director, Lewis Research Center; **Robert R. Gilruth,** to director, NASA's new Manned Spacecraft Center, Houston, Tex.; and **D. Brainerd Holmes,** formerly general manager, Major Defense Systems Div., RCA, to director of the Office of Manned Space Flight Programs. In a realignment of its headquarters technical program offices, **Ira H. Abbott,** director, Office of Advanced Programs, becomes director of the Office of Advanced Research and Technology and **Homer E. Newell,** deputy director, Office of Space Flight Programs, director of the Office of Space Sciences. **George N. Constan** has been named acting manager of the space agency's Marshall Space Flight Center's New Orleans operations.

The Atomic Energy Commission has established three associate directorships in the Div. of Reactor Development, and named **U. M. Staebler** associate director for power applications; **Nelson F. Sievering,** for advanced systems; and **Hugo N. Eskildson,** for operations.

Charles M. Herzfeld has been appointed an associate director of the National Bureau of Standards, responsible for long-range planning and coordination of the Bureau's program of physical standards and measurements.

Ali Bulent Cambel, an ARS Director and professor of mechanical engineering at Northwestern Univ., has been named a Walter P. Murphy Distinguished Professor.

Michael

Cambel

Lee N. Mortensen has been appointed to the new position of manager, Research and Analysis Dept., Wyle Laboratories, and **John R. Herring** has been promoted to manager, engineering and production, West Coast Testing Div.

James R. White has been named program manager of the Satellite Integration Facility of Electro-Mechanical Research, Inc. **William A. Ogletree** becomes general manager of the Sarasota Products Div., and **Earl R. Lind,** systems analyst in the Systems Div. Engineering Dept.

I. Nevin Palley has been elected executive vice-president, Curtiss-Wright Corp. He previously was president of ITT-Federal Laboratories.

Harry R. Wege has been named vice-president and general manager of RCA's newly formed Data Systems Div., Van Nuys, Calif.

Benjamin F. Rose Jr., manager of AEtron Div., has been elected a vice-president of Aerojet-General. **J. W. Keating** has been named manager, Rocket Manufacturing Div., and **Arnold A. Toivonen,** manager, Technical Services Div., both at the Solid Rocket Plant. **James C. Fletcher** and **Frank Lehan** have been appointed president and executive vice-president, respectively, of the new A-G subsidiary, Space-General Corp., which combines Aerojet's Spacecraft Div. and Space Electronics Corp.

Howard W. McFarland has been appointed manager of the Aerospace Propulsion Project Dept., Marquardt.

Frederick C. Durant III, past president of ARS, has been named Washington representative for the Aerospace-Rockets Div., Bell Aerosystems.

F. M. Fulton has been named director of the new Applied Science Div., Hycon Mfg. Co. Fulton formerly was head of the Propulsion Development Dept. and assistant technical director for development at NOTS.

At Rocketdyne, **J. P. McNamara** and **T. E. Myers** have been appointed general managers of the new Liquid and Solid Rocket divisions, respectively, and retain their titles as vice-president. **R. J. Thompson Jr.,** research director, will head the new Research operations; **J. M. Cummings,** the Space Engines operation; and **J. L. Armstrong,** the Nucleonics operation.

The following have been appointed directors of the respective departments at Allied Chemical's General Chemical Div.: **William C. Ruch,** development research; **Robert W. Mason,** laboratory research; and **Charles D. Boyer Jr.,** planning research.

Sidney Krasik has been appointed project manager for Westinghouse Electric Corp.'s portion of the Nerva program, and **N. V. Petrou,** general manager, Air Arm Div.

George C. Dacey has been named vice-president, research, Sandia Corp. **Calvin F. Quate** has left the company to accept the position of professor of applied physics and electrical engineering at Stanford Univ.

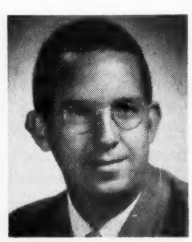
Theodore K. Steele succeeds **Mell A. Peterson** as executive vice-president of Bulova Research & Development Laboratories, a Div. of Bulova Watch Co. Peterson has been appointed as

Rose

Keating

Toivonen

Fletcher



Lehan

Durant

special assistant to company executive vice-president, Kenneth E. Fields.

Lindon E. Saline has been appointed manager, Specialty Devices Operation, General Electric's Defense Systems Dept.; **Edward Ray,** project manager of space power, and **Victor E. Bocelli,** manager, technical facilities planning, both in GE's MSVD Projects Planning and Special Programs Operation. **John M. Heldack** becomes manager, advance projects and marketing, Ordnance Dept.

At GM's Defense Systems Div., **Arnold T. Nordsieck,** Univ. of Illinois physics professor, will head the Technical Specialties Dept.; **William F. Cartwright,** the Weapons and Space Systems Section, Aerospace Operations Dept.; and **George W. Smith,** the Flight Control Group of Weapons and Space Systems Section. **Earl W. Lindveit,** formerly staff member of the U.S. Senate Space Committee, becomes Washington representative for the Division.

Nathan W. Snyder, formerly with the Institute for Defense Analysis, has joined Royal Research Corp. as vice-president and director of research and engineering.

John J. Connolly has been promoted to vice-president, Litton Systems, Inc., and general manager of the Data Systems Div.

John H. Voss has been named president of General Dynamics/Telecommunication, a new division headquartered in Rochester, N.Y., and also a senior vice-president of General Dynamics Corp. **Charles F. Horne** becomes president of the combined operations of GD/Electronics with those of GD/Pomona. Horne is president of GD/Pomona and a senior vice-president of GD.

Robert C. Langford has been named director of the new Kearfott Research Center, West Paterson, N.J., of Kearfott Div., General Precision, Inc.

At Martin Co.'s Orlando Div., **Robert W. Kluge, Sidney Stark,** and **Herman R. Staudt** have been appointed directors of Special Defense Program, advanced systems, and Pershing Ballistic Missile Systems Program, respectively.

William F. Ballhaus has been elevated to executive vice-president of Northrop Corp. **Frederick Stevens** succeeds Ballhaus as corporate vice-president and general manager of its Nortronics Div. **Frank Lynch** becomes vice-president and manager, Electronic Systems and Equipment Dept., and **Ross Miller,** assistant manager and chief engineer of ES&E.

Donald E. Boren has been promoted to manager, data acquisition planning, Pan American's Guided Missiles Range Div., and **John Park** has been named manager, data support planning for the Division.

Lindveit

Snyder

Hopper

Garbarini

At Douglas Aircraft's new Missiles and Space Systems Div., the following appointments have been made: **Jesse L. Jones,** vice-president-deputy general manager and **Robert L. Johnson,** director, product development; **J. L. Bromberg,** director of programs; **J. L. Sigrist,** deputy director of programs; **Peter Horton,** assistant to vice-president-general manager, plans; **C. S. Perry,** chief engineer, missile systems; and **M. W. Hunter,** chief engineer, space systems. Appointed managers of their respective departments are **G. V. Butler,** advanced product planning; **C. C. Walkey,** contracts; **W. H. P. Drummond,** development support; **R. L. Skelton,** facilities analysis; **N. H. Shappell,** manufacturing; **B. I. Maynard,** program analysis; **W. C. Winkler,** product support; and **K. Buchele,** reliability.

Roy A. Olerud and **William B. Croxville** have been named general managers of the Industrial Electronics and Electronic Tube divisions, respectively, at the Allen B. Du Mont Laboratories, Divs. of Fairchild Camera and Instrument Corp.

At Chrysler Corp., **Lovell Lawrence Jr.** has been appointed director, advanced projects organization; **H. Douglas Lowrey,** general manager, Defense Operations Div.; and **James C. Smith Jr.,** assistant general manager, Missile Div. **Grant S. Bennett** has been named chief scientist, acoustics, for the Missile Div.

Grace L. Hopper, originator of electronic computer automatic programming, has been appointed director of systems research, Remington Rand Div., Sperry Rand Corp.

Lester C. Van Atta has been appointed technical director, Hughes Aircraft's research laboratories at Malibu, Calif. He has been on leave of absence as special assistant for arms control for the director of defense research and engineering in the office of the Secretary of Defense.

J. P. Field has been promoted to director of programs, Bendix Mishawaka Div., Bendix Corp., and **E. F. Lapham** and **T. S. Torian** have been named Typhon program manager and Talos program manager, respectively.

Dennis J. Haluza and **Frank W. Jandl** have joined McCormick-Selph Associates engineering staff.

Lorraine S. Gall has been named a specialist microbiologist at Republic Aviation's Research and Development Center's Space Environment and Life Sciences Laboratory. **H. C. Towle** becomes manager of the company's newly formed Systems Integration Section.

Royal Weller has been named director of engineering for the Space Systems Div. of Lockheed Missiles and Space Co.

S. Dean Wanlass has joined Packard Bell Electronics as group vice-president, Defense and Industrial Group.

Frederic M. Cooper, director of engineering, has been promoted to vice-president and general manager of Amcel Propulsion, Inc.

Graham B. Brown has joined Stauffer Chemical Co. as general manager, Metals Div.

Stanley M. Smolensky has been appointed general manager, National Electronics Div., Thiokol Chemical Corp., and also will be responsible for coordinating marketing activities for the company's new Trackmaster program.

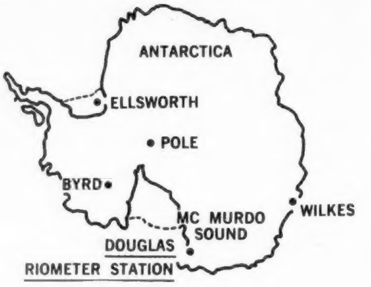
Joseph A. Waldschmitt has been elected president and chief executive officer of Page Communications Engineers, Inc., subsidiary of Northrop Corp. **Richard E. Horner,** Northrop senior vice-president, has been appointed to the Page board. **Gail E. Boggs** becomes director of research and development at Page.

Robert F. Garbarini has been appointed chief engineer of Sperry Gyroscope's Air Armament Div.

Lt. Gen. Clovis E. Byers (Army-Ret.) has been named vice-president, Washington, D.C., office for General Telephone & Electronics Corp. ♦♦

Radiation Station for Antarctic

Solar flare radiation characteristics will be studied at a research station which Douglas Aircraft will establish in the Antarctic late this year in cooperation with the National Science Foundation. The facility is a part of a program to determine the seriousness of solar-flare radiations to astronauts. Douglas scientists will man the station, which will be located in the McMurdo Sound region of the Antarctic.



Hypersonics Conference

(CONTINUED FROM PAGE 39)

about a spherical nose and found that such a self-similar approximation resulted in errors in shock stand-off distance of as much as 20%.

The final paper of the morning session, by F. K. Moore and W. J. Rae, titled "The Rayleigh Problem for a Dissociated Gas," considered a semi-infinite domain filled with a partly dissociated diatomic gas, initially at rest and in equilibrium. The bounding plane, represented in the sketch from their paper on page 38, is a solid surface with some given level of catalytic efficiency for recombination, initially at rest and at the same temperature as the gas. At some instant this surface is set impulsively in motion, thereby establishing a new constant condition at the surface. This action produces chemical non-equilibrium in a boundary layer which grows, with time, outward from the plate. The governing equations are linearized by assuming small disturbances throughout.

The general features of the heat-transfer results obtained for a temperature jump at a stationary wall are qualitatively the same as that found by Fay and Riddell in their calculations of the non-equilibrium stagnation-point boundary layer. If, instead, the plate temperature is held constant and the plate is set into motion, the atom concentration at the surface, and hence the heat-transfer coefficient, is the same both early and late in the time history of the flow. However, at intermediate times a transient dip in the heat-transfer coefficient results. On the basis of presumed analogy between the Rayleigh problem and the flat-plate problem, it was tentatively suggested that heat-transfer rates may not be greatly influenced by non-equilibrium effects. It should be pointed out, however, that this conclusion was made on the basis of a small-perturbation analysis and an assumed Lewis number of unity, and hence may not be completely realistic.

The chairman of the Wednesday afternoon session on experimental techniques was Peter P. Wegener. The first paper by J. Lukasiewicz, J. D. Whitfield, and R. Jackson, was titled "Aerodynamic Testing at Mach Numbers from 15 to 20," and concerned the current status of the von Karman Gas Dynamic Facility "Hotshot" tunnels. Experimental results were presented concerning surface pressure distributions and drag measurements on simple two-dimensional and axisymmetric bodies as obtained with these facilities. It was indicated that the flow contamination associated with the direct heating of the working gas by an electric arc has been significantly reduced and that, while heat-transfer measurements still indicate considerable scatter, satisfactory force and pressure measurements can be obtained. Pressure-distribution data from slender blunted cones revealed the expected over-expansion and pressure overshoot along the conical surface, while drag data for cold-wall conditions exhibited drag levels as high as 15 times the inviscid drag, indicating very strong viscous-interaction effects.

The second paper, "The Duration and Properties of the Flow in a Hypersonic Shock Tunnel" by D. W. Holder and D. L. Schultz, offered a very good discussion of the shock tunnel and indicated that, in spite of the brevity of the useful test time, significant results can be obtained if the tunnel is suitably designed. The dependence of the test time on such factors as the flow duration at entry to the expansion nozzle, the losses of testing time associated with the nozzle expansion process, and the establishment of steady flow past the model were considered. Also discussed were the dependence of test-flow properties on such factors as nozzle boundary-layer growth and the extent to which recombination or de-ionization occur in equilibrium with the local temperature when the flow is expanded. Very detailed results were given for cases where the shock tunnel was not operated under the usual tailored conditions.

A typical calculated wave pattern for shock-tunnel operation from this paper appears on page 39, together with the associated pressure changes at the nozzle entrance. The figure indicates that after the first reflected disturbance successive disturbances are weak; the contact surface is brought effectively to rest and the pressure rapidly approximates the value computed on the assumption that the flow behind the first transmitted shock is brought isentropically to rest. These results suggest that if the time after the first reflected disturbance is used for test purposes, long running time can be achieved by reflected-shock operation even under conditions far removed from tailoring. The flow establishment past flat-plate models for dump chamber pressures of as low as 1 micron of mercury was illustrated by Schlieren photographs of remarkable clarity.

The third paper, "An Evaluation of the Hypersonic Gun Tunnel" by K. N. C. Bray, was devoted to a critical evaluation of the free-piston-compression hypersonic wind tunnel. It was shown that, although early performance calculations were considerably over-optimistic, and the stagnation temperature is limited by piston strength requirements to values too low for the study of significant real-gas effects, such a facility may offer useful advantages in convenience and economy because of the comparatively long running time which may be obtained.

Wind-Tunnel Discussion

The fourth paper, by L. Talbot and F. S. Sherman, on "Diagnostic Studies of a Low Density Arc-Heated Wind Tunnel Stream," was a characteristically interesting and well-presented discussion concerning some aspects of the operation of such a facility. Unfortunately, due to the fact that the data presented had been obtained only a week previous to the conference, no preprints of this talk were available. Of particular interest were the electron density and temperature measurements obtained with the aid of a unique "double Langmuir" probe. The results were shown to agree with microwave measurements. Static-pressure surveys in the test section indicated an increase in pressure away from the centerline, possibly due to the chemistry of the flow.

The final paper of the afternoon, "Initial Results from a Low Density, Hypervelocity Wind Tunnel" by J. L.

Potter, M. Kinslow, G. D. Arney Jr., and A. B. Bailey, concerned initial experiments designed to determine the characteristics of the flow in such a facility. Low Reynolds number effects on water-cooled impact pressure probes and static-pressure probes were shown. Preliminary work with a probe designed to measure local mass flow rate was outlined, and the results were shown to be in agreement with impact and static-pressure measurements. The extent of the boundary-layer growth in the nozzle was shown to be characteristically large, the diameter of the useful core of uniform flow being approximately one-sixth of the nozzle-exit diameter. Some rather unusual data were presented, indicating that a diffuser would be advantageous even for the very low Reynolds numbers characteristic of the facility. A useful correlation of data on sphere drag was included.

E. L. Resler Jr. served as chairman of the Thursday morning session, devoted to theoretical analyses of chemical kinetic effects in hypersonic flow.

S. H. Bauer in the opening paper, "Chemical Kinetics: A General Introduction," presented a lucid account of the fundamental assumptions which are usually introduced to obtain the chemical kinetics required in gas dynamics. The relationships between experimentally determined quantities and molecular parameters were discussed. Emphasis was placed on the diversity of phenomena encountered in the various gas-dynamic regimes. It was stated, for example, that in the low-density regime one should describe the system in molecular variables only; the chemical rate constants would then be replaced by averages over differential collision cross-sections (which are extremely sensitive to the molecular structure and the details of the collision). The advantage of the coupling of gas dynamics and chemistry was discussed and it was shown by means of selected examples that both disciplines can contribute a great deal toward a complete exposition of the dynamics of fluids at high temperatures.

High-Temperature-Air Results

The second paper, "Chemical Kinetics of High Temperature Air" by K. L. Wray, presented a fairly comprehensive review of recent work carried out at the Avco/Everett Research Laboratory and by other workers in the field. Rate constants for eight significant reactions of the species N_2, O_2, N, O, NO, NO^+, and e^- were determined on the basis of an evaluation of all available data. Computed concentrations and density- and temperature-time histories behind a normal shock were presented for three shock speeds. The regimes of importance of the various processes were discussed. In the discussion which followed, Glick of the Cornell Aeronautical Laboratory mentioned that the constant for the electronic reaction was not in agreement with their measurements, and emphasized the need for further experiments.

The third paper of the morning, "Chemical Effects in External Hypersonic Flows" by R. Vaglio-Laurin and M. H. Bloom, was an omnibus treatment of the external aerodynamics associated with axisymmetric bodies in a continuum, at flight conditions where local chemical equilibrium does not prevail. A simplified analysis of the significant effects was presented which will be extremely useful in hypersonic aerodynamic design. The flows considered were characterized by the existence of Rankine-Hugoniot shocks and distinct viscous and inviscid regions. An inviscid analysis was presented wherein the gas crossing the strong portion of the shock is assumed chemically frozen at near sonic velocity, while the gas crossing

the weaker portions is considered frozen at post-shock equilibrium conditions. A combination of these calculations with one-dimensional rate calculations along streamlines led to reasonably accurate results for the inviscid portion of the flow. A qualitative discussion of the behavior of non-equilibrium boundary-layer flow was presented and a quantitative study of laminar and turbulent wakes, including the influence of both the inner core and shock-induced vorticity, was considered. An order-of-magnitude analysis for radiation and wake-region unsteadiness effects—two phenomena which are only beginning to receive serious attention—has been carried out.

The fourth paper, "Flow of a Reacting Gas" by V. A. Langelo, presented computations of non-equilibrium oblique shock profiles and the associated downstream histories, as carried out by a stream-tube technique. The results were compared with equilibrium results determined in the same general manner.

C. E. Treanor, in a paper concerning "Radiation at Hypersonic Speeds," presented an excellent review of the data available for radiation from equilibrium high-temperature air. Several graphs of the absorption coefficients for the component species were shown. A large disagreement for some of the band systems was noted. In answer to a question by M. Bloom concerning the effect of these discrepancies on the bulk phenomenological emission coefficient, Treanor estimated a factor of three.

The final paper of the morning session was "Radiation From a Non-Equilibrium Shock Front" by J. D. Teare, S. Georgiev, and R. Allen. An experimental investigation for non-equilibrium radiation from pure nitrogen and from air behind normal shocks with velocities up to 35,000 fps was presented. Results were given for two band systems. The non-equilibrium radiation effects on bodies re-entering at supersatellite velocities were computed, and were compared with equilibrium radiation and convective heating.

Other Interesting Papers

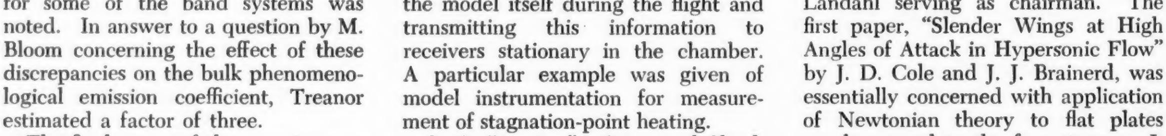
Henry T. Nagamatsu served as chairman of the Thursday afternoon session on experimental techniques. The first paper, "The Free Flight Range: A Tool for Research in the Physics of High-Speed Flight" by A. C. Charters, was an interesting presentation of some of the problems involved in modifying range techniques, originally developed for determining artillery-projectile characteristics, so that such facilities would be useful for hypersonic flight tests. The development of adequate launchers was discussed and the performance of a particularly effective accelerated-reservoir light-gas gun, diagrammed on page 39, was presented in some detail. This gun has been used to fire models at velocities between 20,000 to 30,000 fps with surprisingly small erosion of the gun barrel. Development of necessary instrumentation was considered, not only for the flight-test chamber, but also for making measurements on the model itself during the flight and transmitting this information to receivers stationary in the chamber. A particular example was given of model instrumentation for measurement of stagnation-point heating.

S. C. Lin, in "A Survey of Shock Tube Research Related to the Aerophysics Problem of Hypersonic Flight," presented a compendium of work carried out at the Avco/Everett Research Laboratory with this type of facility. Its usefulness as a source of high-temperature air in spite of its relatively low Mach number was emphasized.

The third paper, "Air Arc Stimulation of Hypersonic Environments" by W. R. Warren and N. S. Diaconis, described the performance of various types of arc generators. A recently developed tandem Gerdian arc unit was discussed in some detail, and calibration results were described. The unit operates at very low contamination levels when used to drive an arc tunnel.

A. Hertzberg, always a delight to have as a speaker, excelled in the final presentation of the afternoon. In a paper, "The Development of the Shock Tunnel and its Application to Hypersonic Flight," he described the probable future development of such facilities. He reported on some recent calculations by the Cornell Aeronautical Laboratory group led by J. G. Hall of exact solutions for non-equilibrium expansions of air with coupled chemical reactions. There is no doubt that this work (available as CAL Report AF-1413-A-1) will remain a standard reference for some time to come.

The final session of the conference, held on Friday morning, was devoted to theoretical treatments of inviscid hypersonic flows, with Marten T. Landahl serving as chairman. The first paper, "Slender Wings at High Angles of Attack in Hypersonic Flow" by J. D. Cole and J. J. Brainerd, was essentially concerned with application of Newtonian theory to flat plates nearly normal to the free stream. It should prove to be quite useful for lifting re-entry vehicle aerodynamics. The analysis is basically two dimensional, the results being applied in spanwise strips for slender flat wings. Heat-transfer calculations were carried



Left, general chairman for the ARS-AFOSR International Hypersonics Conference, Frederick R. Riddell of Avco, welcomes participants in the meeting. Center, Lester Lees of the California Institute of Technology sets the first session in motion. Right, Haruko Oguchi of Tokyo Univ. delivers the first paper of the meeting, "Density Behavior Along the Stagnation Line of a Blunt Body in Hyperthermal Flow."

out on the basis of boundary-layer theory with Newtonian external flow conditions. The results for angles of attack differing slightly from 90 deg were calculated by what essentially amounts to a perturbation procedure; that is, a correction factor, small compared to the 90-deg Newtonian solution, was calculated. As the local angle of incidence is everywhere nearly 90 deg, the usual low pressure difficulties associated with curved surface Newtonian theory are avoided, and the results should be realistic. Indeed, fair agreement with experimental results for delta wings was found. It was brought out in the discussion that, as the angle of attack is sufficiently decreased, the shock will attach at the apex; then the use of this spanwise strip theory would not be proper. Rather, an appropriate conical flow analysis would be required.

The second and fourth papers, "On The Newtonian Theory of Hypersonic Flow at Large Distances from Bluff Axially Symmetric Bodies" by N. C. Freeman and "A Theory of Entropy Layers and Nose Bluntness in Hypersonic Flow" by J. K. Yakura, became involved in what was probably the liveliest discussion of the entire conference. Both papers were concerned with finding a uniformly valid solution far downstream from the blunt nose of a slender body. Freeman used the direct approach of calculating a shock for a specified body, while Yakura solved the inverse problem where the shock is specified and the body is calculated. Both papers recognize the existence of two separate regions of flow: An inner entropy layer next to the body, originating from that portion of the flow which passes through the blunt portion of the shock, and characterized by high temperatures and small pressure gradients, and an outer layer next to the shock characterized by relatively cool temperatures.

Fundamental Assumption

Freeman's approach was to extend the Newtonian free-layer solution, known to be valid near the nose, in such a way that it becomes uniformly valid far downstream. He made the fundamental assumption that this validity is insured if the solution approaches the "blast-wave" solution—and herein lies the point of controversy.

Yakura, on the other hand, made use of the similarity between the behavior of the entropy layer and a boundary layer and developed asymptotic expansions for both the inner and outer regions of flow. He further claimed that the blast-wave analogy is invalid within the entropy layer, a statement in direct contradiction to Freeman's approach. Numerical results were presented indicating that a paraboloidal shock is produced by a blunt body which grows as a small power of x, rather than by the Freeman's hemisphere-cylinder configuration. While the nature of Yakura's inverse method prevents the direct determination of the shock shape for a hemisphere-cylinder body, his results nevertheless appear to be consistent with the numerical calculations of V. Van Hise, which gave a power-law exponent of 0.46, at a specific heat ratio of 7/5, for the shock shape associated with a hemisphere cylinder.

The discussion following the two papers concerned mainly the fundamental question of blast-wave validity far downstream. Van Dyke objected to Freeman's assumption of blast-wave validity and referred to the results of both Van Hise and Sychev for support. H. K. Cheng felt that the reliance on numerical results, such as those of Van Hise, which were only carried a finite distance downstream to distinguish between expected exponents of 0.46 and 0.5 infinitely far downstream, were not satisfactory, and that such numerical results might indeed approach a value of 0.5 if carried far enough. J. Cole referred to L. Sedov's book, saying that if asymptotic flow fields due to point singularities are studied according to hypersonic small-deflection theory, there are actually two solutions, one being the blast-wave solution, and another giving an asymptotic power-law exponent of 0.46. He attributed this second solution to the influence of the large entropy layer thickness.

The third paper of the session, "Shock Layer Structure and Entropy Layers in Hypersonic Conical Flows" by R. E. Melnik and R. A. Scheuing, was concerned with the entropy layer associated with non-axisymmetric conical flows in the thin-shock-layer limit. Solutions have been found in an extended region including the entropy layer, but excluding certain small regions near cross-flow stagnation points.

In conclusion, the conference was distinguished by both the excellent quality of the papers and the significant and timely nature of the subject matter covered. A great deal of useful material was presented, both of a theoretical and an experimental nature. The discussion accompanying the theoretical papers was particularly lively. The only disappointing aspect of the conference was the cancellation of the session at which papers from the USSR were to have been presented. ♦♦

ASTRONAUTICS Data Sheet — *Propellants*

Compiled by Stanley Sarner, *Thiokol Chemical Corp., Elkton Div., Elkton, Md.*

NITRONIUM PERCHLORATE, NO_2ClO_4

Nitronium perchlorate is a high density, energetic solid oxidizer of current interest. It is being considered as a replacement for NH_4ClO_4 in some applications. It may also prove useful as an intermediary in the synthesis of new oxidizers. It is a fairly stable white crystalline powder, which is hygroscopic, but has shown no more than 2% decomposition in six years when stored away from moisture.

Hazards

The pure material is not overly sensitive, however impurities (including moisture) cause sensitivity to shock. When exposed to air it hydrolyzes to nitric and perchloric acids which pose some toxicological problems.

Complete eye protection and protective gloves (not rubber) are recommended. Spills or dust should be promptly cleaned up with large quantities of water.

Materials for Handling

Very little is known about the compatibility of NO_2ClO_4. It has been stored in glass for as long as six years, but information on other materials is lacking.

Cost and Availability

Only research quantities are now available, however it is expected that large scale production will follow.

Properties of NO_2ClO_4

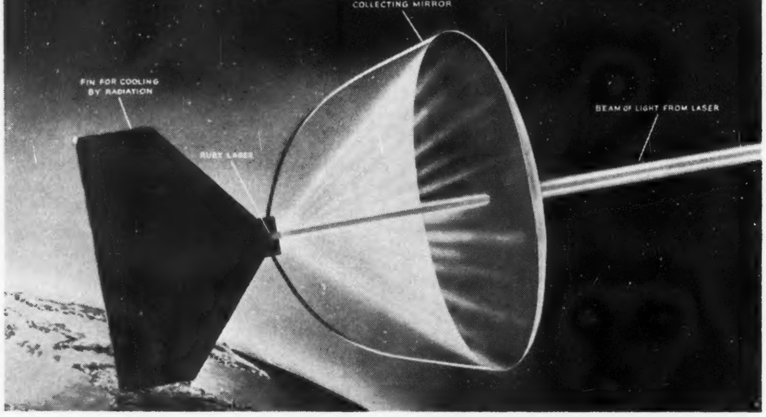
Initial Decomposition	95–100 C	203–212 F
Decomposition Temperature	120–140 C	248–284 F
Crystal Density at 25 C	2.25 g/cm³	140 lb/ft³
Bulk Density (can be compressed)	0.4 g/cm³	25 lb/ft³
Vapor Pressure at 25 C	less than 0.05 mm	
Heat of Formation at 25 C	+8.0 ± 0.4 kcal/mole	
Shock Sensitivity	no detonation at 250 kg-cm	
Storage Stability	less than 2% decomposition in 6 yr	

Theoretical Performance of NO_2ClO_4*

	Specific Impulse (sec)		Chamber Temperature
Fuel	Frozen Flow	Equilibrium Flow	Deg K**
H_2	346	349	2713
BeH_2	334	346	3394
AlH_3	292	305	4175
B_5H_9	289	302	4432
N_2H_4	285	295	3363
UDMH	276	289	3540
CH_2	264	278	3586
C_4N_2	270	276	4272
MgH_2	246	263	3114
LiH	253	258	3292

* Pc = 1000 psia; Pe = 14.7 psia; optimum O/F ratio.

** Corresponds to equilibrium flow impulse.



Sun-Powered Laser Under Study

Artist's conception of sun-powered laser, under development by American Optical Co. under an AF contract. Structurally, the proposed laser will be a pink ruby rod with partially reflecting ends. By using a solar collector, it is expected that sufficient light can be produced to cause the rod to go into continuous laser oscillation.

Attitude Control of Spacecraft

(CONTINUED FROM PAGE 28)

moon, and, after all plates were exposed, set the vehicle in rotation again. It is possible, however, that pictures of a quality similar to those transmitted by Lunik III could have been obtained using a photosensitive cell mounted on a spinning satellite, a method described in several places in the literature.[6]

The earth's magnetic field was used both as a de-spin actuator and as a reference frame in the Transit satellites. On Transit 1-B, coarse de-spin was obtained by weights paid out on cables, while rods with large hysteresis losses opposed the residual rotation. When the spin rate was reduced to 0.01 rps, a strong permanent magnet was able to align the spin axis parallel to the earth's magnetic field and stabilize the vehicle.[7]

The Tiros satellites are spin-stabilized in orbit and, in addition, Tiros II and III are equipped to use the magnetic field of the earth for actuation torque. As a follow-on to Tiros, the Nimbus satellites will be placed in polar orbits. Their cameras must be maintained in an earth-referred attitude to within 1 deg about any axis with a drift rate of less than 0.5 deg per sec. For these requirements, the following system elements were chosen: Three flywheels, two infrared horizon scanners to determine the vertical, a sun sensor for coarse yaw sensing, an integrating gyro for fine yaw sensing, a fine sun-sensor to detect gyro drift, eight compressed-gas jets, and a 4-lb digital computer.[8]

Placing a man in an earth satellite can allow greater control system flexibility. This will be the case in the Dynasoar spacecraft, where the pilot will be an essential part of the system. On primitive vehicles, such as the Mercury capsules, the astronaut is not essential, even though he can completely control the attitude of his vehicle.

The Mercury astronaut has two completely redundant control and sensing systems at his disposal. His autopilot and six jets can carry out a successful mission without his aid, or he may choose to take over some phase of the task. He has three means to provide manual control—a "fly-by-wire" system, which is an "off-on" control over the six jets of the automatic control system; a proportional acceleration system, which opens the valves of three other jets in proportion to stick displacement; and a proportional-rate system, which results in capsule rate proportional to stick displacement, using these same three jets.

Provision is made for three attitude-reference systems, two of which are external. There is a display of rate indicators and attitude indicators sufficient for a successful mission. The astronaut may choose to center the image of the earth in his telescope to obtain pitch and roll indication and to check terrain drift for yaw sensing. The third method is the capsule window, through which he may sense roll and pitch by checking the horizon and yaw by noting the drift of the stars.[9]

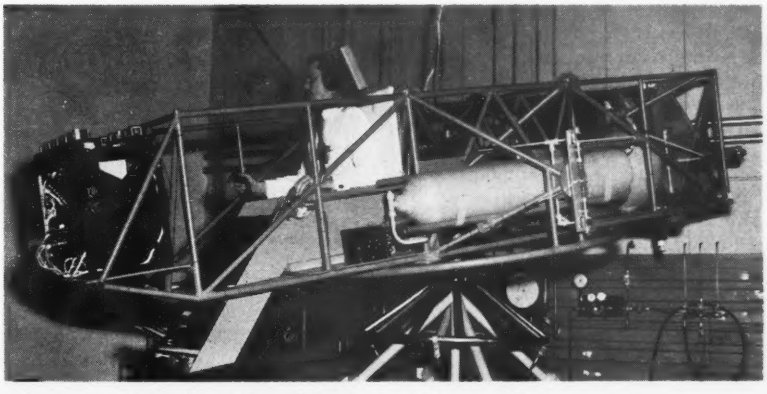
The proposed NASA Orbiting Astronomical Observatory will need extremely precise control. Requirements here call for less than 0.1-sec-of-arc drift and 0.1-sec-of-arc-per-second drift rate, both about all three inertially fixed axes. Accurate injection into orbit will permit six flywheels to provide all of the necessary actuation torque. Rate sensing will be by rate gyros, while six sun-sensors provide coarse attitude sensing. Six star trackers then lock onto preselected stars; their redundancy improves accuracy through a statistical analysis of the readings.[10]

The difference between system components for earth satellites and space probes is not great. The Ranger lunar-impact vehicle, for example, has nitrogen-jet actuators, rate gyros, a sun finder and sensor system, and an earth center-of-illumination tracker. Signals from the earth will provide information for midcourse manuevers and thrust vector orientation.[11]

On other future space vehicles—such as Surveyor, Prospector, Mariner, Voyager, and Apollo—the attitude-control systems will of necessity be superior to anything now in operation. Nevertheless, the basic concepts of the sensing and actuating devices do not seem destined for any radical changes.

In discussing the hardware of attitude control, it is best to examine the subject in a realistic and practical manner. There are indeed some exotic schemes which have a certain wild appeal, but serious proposals to utilize these techniques in vehicles which are now scheduled or proposed should be viewed critically.

The yaw gyro is probably the simplest and most feasible method for sensing yaw angle.[12] It may be either a single- or two-degree-of-freedom gyro with its spin axis normal to the orbit plane. There are no coupling effects in the two-degree-of-freedom instrument, but the steady-state output of a single-degree-of-freedom integrating gyro contains roll-angle components that must be subtracted by processed signals from a roll horizon scanner to yield yaw-angle data. Mini-



Chance Vought Simulator in Operation

This automatic controls evaluation simulator has gone into operation at the Astronautics Div. of Chance Vought Corp. The simulator, to be used in developing spacecraft control systems, floats on an air bearing. Here, R. M. Johnson of CV Astronautics puts the simulator through its paces.

NEREM Again in Boston

The Northeast Electronics Research and Engineering Meeting takes place this month from the 14th to 16th at Commonwealth Armory and Somerset Hotel in Boston, Mass., with an extensive exhibition and 23 technical sessions involving some 90 papers on coherent light, information theory, satellite communications, radio astronomy, automatic controls, molectronics, atomic frequency and time standards, etc. C. H. Townes, new provost of MIT, will address the banquet audience.

mum rate-sensing capabilities tend to limit the usefulness of this instrument to close orbits.

For measuring rates, the single-axis rate gyro seems best. It usually is employed to generate attitude rate-damping signals for the control system. Gyros are chosen here on the assumption that they can be designed to meet the environmental and life requirements. Most failures in high-quality inertial gyros using ball bearings for spin-axis support are caused by failure of the bearing retainer or lubricant. Heavy preloading and marginal lubrication of the bearings contribute greatly to reducing drift and shortening life in a terrestrial environment. In a weak gravitation field, anisoelasticity and mass shifts become less of a problem. This allows lighter preloading and, consequently, the lubrication may be increased or reduced depending on whether long life or low power is required. Though weak gravitational fields help to increase gyro life, most space missions will require that very low rates be sensed. Thus there is a limit to the "looseness" allowable in the bearings and the amount of lubricant that can be used. In addition, the bearing materials and lubricants must be studied in this new environment to determine the effects of radiation and high vacuum on performance.

The vertical can be most readily determined by the use of horizon scanners. The horizon-sensor art has been strained severely by the requirement for greater earth-pointing accuracy on some of the more sophisticated missions. High accuracy and long life, together with low power consumption, are not generally compatible with some of the scanning means now proposed and employed.

Many different embodiments of motor-driven scan have been suggested, including rotating mirrors, prisms, and lenses. These motors, with their bearings exposed or potentially exposed, are a weak link because of sealing difficulties. To circumvent the bearing problem, nodding and nutating means, in which only a flexing action occurs in the exposed moving parts, may be tried.

The sun is a potential hazard when using a horizon sensor. Depending on the flight path or orbit of a vehicle, the sun may be viewed on or near the horizon or at some other place in the scan. When this occurs, necessary logic must be incorporated into the design to preclude false signals or damage to the sensor. Spurious reflections and images from this very powerful I.R. source can be a problem analogous to that found in optical systems operating in the visible region. Needless to say, the correction of these interferences is often very difficult.

There is also the problem of an inherently noisy horizon spectrum. Very little can be done about this noise directly. Attempts at smoothing the signal by conventional filter techniques introduce undesirable delays. Auxiliary rate sensing by means of gyros can be incorporated, but at the price of additional system complexity. Processing the signal from the sensor head by digital or, indeed, by any other means can at best only eliminate errors and noise that are added after sensing, but can do nothing about noise and inaccuracies inherent in the signal itself.

New Methods

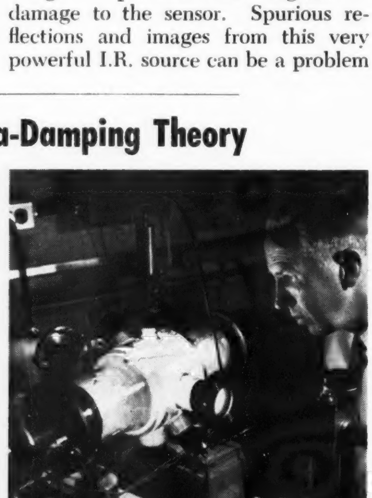
Methods of electronic scanning involving no moving parts, similar to techniques employed in television, have been proposed. These methods hold much promise. Present difficulties stem from the lack of a sensing means having the desired sensitivity and time constant in the I.R. region. Recent papers indicate, however, that these difficulties are being overcome and that these methods are gaining favor.

It has been proposed that the vertical be sensed inertially by the use of accelerometers fixed in the vehicle.[13] The gravity gradient will cause a different output from the various accelerometers. Unfortunately, so will many other things, including accelerometer temperature, material instability, power-supply variations, etc. These undesired effects are generally several orders of magnitude larger than the desired gravity-gradient effect. There is the further complication that for the present, at least, this system would have to be checked out and adjusted in the presence of a 1-g earth field.

A possibly more elegant means of sensing the gravity gradient is to use a form of pendulous accelerometer. Anything in orbit or free fall will tend to align itself with its minor axis of inertia along the vertical. For a vehicle weighing several hundred pounds, restoring torques on the order of ounce-inches per radian can be obtained with acceptable vehicle configurations. The pendulum gravity gradient sensor would be much smaller and would be located within the vehicle. Its function would be solely to sense the gradient of gravity and, by means of a suitable pickoff, to transmit this information to whatever actuator system is aboard.

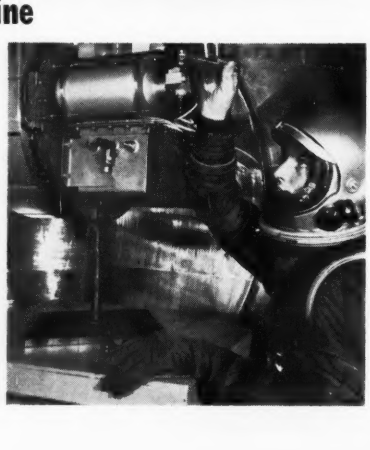
Again, one must face reality. The available torque to bearing or pivot

Experiment Verifies Plasma-Damping Theory



Melvin J. Kofoid of Boeing Scientific Research Laboratories poses with plasma chamber in which he demonstrated self-damping of electron-beam-induced oscillation in a plasma, thus providing the first experimental verification of the damping theory advanced by the Russian physicist L. D. Landau in 1945 and since become an important ingredient of fusion research. Dr. Kofoid gave a brief verbal account of his experiments at the recent International Conference on Plasma Physics and Controlled Nuclear Fusion at Salzburg, Austria.

Republic Shows Plasma Engine



A technician readies Republic Aviation's "pinched plasma" engine for its first public demonstration. This model of the engine contains a battery power supply that can be linked with a solar-cell array. Republic expects to have a flight-test model ready early in 1962. At the ARS-Northwestern MHD conference (see page 40), Alfred Kunen said the engine showed virtually no erosion of components in long test runs at the AF Aeronautical Systems Div. The engine development is sponsored jointly by Republic, ONR, and AFOSR.

friction levels are quite small, and the device must work in a 1-g field for test, adjustment, and checkout purposes. A magnetic suspension or gas bearing can be tried for pivoting, but the outlook is not very promising. It is interesting that a pendulum not only has been proposed as a sensor but as the erection reference for a gyro system.[14] The pendulum pivots or bearings for this application were not specified.

An attitude-sensing system consisting of horizon scanners, a yaw gyro, and rate gyros will provide an optimum system for most earth satellites. For long-term applications in which the rate gyros might fail, a new device holds promise of replacing them. It is called a celestial rate sensor. When fully developed, it will be able to perform any function now done by rate gyros. Celestial rate sensors utilize the fact that the drift velocity of the stars as seen by a body-fixed telescope is the negative of the angular velocity of the vehicle about an axis normal to the drift direction.[15]

When extreme accuracy is required, a star sighter must be used. In ordinary telescopic systems, 10 sec is the maximum pointing accuracy because of the limitations of the telescope gear drives. Precision equipment can eliminate this problem and make the pointing accuracy a function of the diameter of the principal maximum of the diffraction pattern, which is about 1 sec of arc for a 4-in. telescope. Techniques have been developed for working within the diffraction pattern to obtain accuracies of the order of 0.1 sec as required by the Orbiting Astronomical Observatory.[16] The primary application of star telescopes will be in interplanetary travel, where an inertially fixed orientation is desired. For rotating reference frames, a considerable amount of computation must be performed; and the system, especially for earth-referred vehicles, becomes considerably more complex.

Angle-of-attack devices sensing the residual atmosphere, radiation fields, or particles, find only a few possible applications. Center-of-illumination trackers are very important, potentially giving a pointing accuracy of less than 1 min of arc.[3]

For most missions, it seems that the best actuator system will involve some combination of jets and rotating internal parts. The latter are of two primary types: Reaction wheels and single-axis gyros. The reaction wheels are at present more developed than the single-axis gyro system.[3] The latter offers the possible advantage of lower power requirements for a pure damping function. Both systems have spinning parts, and therefore coupling exists between the axes. A reaction sphere has been proposed to remedy this. This is a sphere suspended either by magnetic[17] or electrostatic[18] means, with provision made to torque it about three orthogonal axes. Problems such as those associated with the suspension system must still be overcome.

Further Problems

Problems involved with gas-jet control involve such things as gain nonlinearity (gain stabilizing negative force feedback being difficult to apply), leakage, cold welding of valve to seat, freezing of the valve mechanism, or other temperature problems. Corrosion of valve parts can be another annoyance, especially in a system using hypergolic propellants.

The gravity-gradient torque is also an actuator torque and is helpful if an earth-referred orientation is desired. The other methods of actuation are restricted to particular applications. In close orbits, the earth's atmosphere can be used to produce a torque, while solar radiation becomes an important torque for heliocentric orbits. These last three torque sources are present, of course, at all times. The question is whether their magnitudes are high enough in a particular mission so that they may be used to advantage by proper vehicle design.

The use of the earth's magnetic field as an actuator and damper presents some inherent difficulties, the principal one being the inability to generate a torque without cross-coupling effects and the inability to provide a torque parallel to the magnetic field. To solve the latter problem, it has been proposed that a reaction wheel be used to yield an auxiliary torque. The magnetic field can also be used in the place of jets to de-saturate inertia wheels.

References

1. Roberson, R. E., "Attitude Control of a Satellite Vehicle—An Outline of the Problems," *Proceedings of VIIIth International Astronautical Congress, Barcelona*, 1957.
2. Button, P. A., Mallory, P. E., and Boor, S. B., "V/H Satellite Attitude Control," *Proceedings of the National Specialists Meeting on Guidance of Aerospace Vehicles*, Boston, 1960, p. 114.
3. Roberson, R. E., editor, "Methods for the Control of Satellites and Space Vehicles—Volume I: Sensing and Actuating Methods," WADD TR-60-643, Vol. I.
4. Stafford, W. H. and Croft, R. M., "Artificial Earth Satellites and Successful Solar Probes, 1957-1960," NASA TN D-601, p. 230.
5. Sykes, J. B., translator, "The Other Side of the Moon."
6. Sonnet, C. P., "Space Vehicle Television," *Record of National Symposium on Extended Range and Space Communications*, pp. 4-19.
7. Fischell, R. E., "Magnetic Damping of the Angular Motions of Earth Satellites," ARS Preprint 1502-60.
8. Alexander, G., "Nimbus Uses Wheels, Jets for Control," *Aviation Week*, July 10, 1961, p. 77.
9. Voas, R. B., "Project Mercury: Human Factors in the Manual Control of Attitude in the Mercury Vehicle," ARS Preprint 1402-60.
10. Anderton, D. A., "Grumman's Orbiting Observatory Design Progresses," *Aviation Week*, Feb. 13, 1961, pp. 54-63.
11. Stambler, I., "Ranger: First U.S. Moon Impact Vehicle," *Space/Aeronautics*, Feb. 1961, p. 45.
12. Roberson, R. E., "Attitude Control of Satellites and Space Vehicles," *Advances in Space Science*, Vol. 2, p. 403.
13. Carroll, J. J. and Savet, P. H., "Space Navigation and Exploration by Gravity Difference Detection," IAS paper 59-91.
14. Chatkoff, M. L. and Lynch, L. G., "Attitude Control of a Space Vehicle by a Gyroscopic Reference Unit," *Aero/Space Engineering*, May 1960, p. 66.
15. Karrenberg, H. K. and Roberson, R. E., "Celestial Rate Sensing," *ARS Journal*, March 1961, p. 440.
16. Von Pahlen-Fedoroff, G., "An Accurate Determination of Attitude by Optical Means for Applications in Space Vehicles," *Proceedings of the National Specialists Meeting on Guidance of Aerospace Vehicles*, Boston, 1960 p. 40.
17. Haeussermann, W., "Comparison of Some Actuation Methods for Attitude Control of Space Vehicles," *Proceedings of Manned Space Stations Symposium*, Los Angeles, 1960, pp. 267-274.
18. Ormsby, R. D., "A Free Reaction Satellite Attitude-Control System," *Proceedings of the National Specialists Meeting on Guidance of Aerospace Vehicles*, Boston, 1960, p. 53. ◆◆

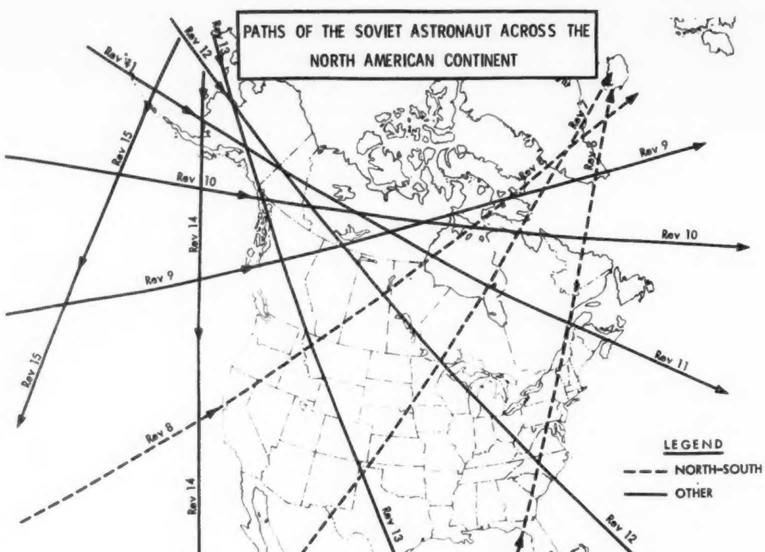
Fins Steer Redeye

Redeye with 15-deg-cant in-out fins for steering.

Small fins that pop out and retract on command from a heat-seeking guidance system make course corrections for Redeye, the shoulder-fired anti-aircraft missile being developed by General Dynamics/Pomona with the Army and Marine Corps. The missile spins in flight. The time of fin extension determines the amount of turn. The round weighs less than 20 lb and measures about 4 ft long and 3 in. in diam.

Status of Refractory Metals Sheet Rolling Program

The NAS-NRC Materials Advisory Board reports on the status of the Refractory Metals Sheet Rolling Program in Report No. MAB 172-M, available from its Div. of Engineering and Industrial Research, 2101 Constitution Ave., Washington 25, D.C. The report sets forth the most promising approaches to speed development of alloys of molybdenum, columbium, tantalum, and tungsten that will find important applications in rocket nozzles, space vehicles, etc.



Where Titov Went

The North American Air Defense Command's Space Detection and Tracking System, located at NORAD's headquarters in Colorado Springs, Colo., picked up the Vostok II carrying Russian Cosmonaut Gherman S. Titov shortly after it was launched on August 6. According to Philco Corp., the System's Philco 2000 computer permitted a projection of Titov's first pass over the East Coast four hours in advance and, after the Vostok II's first orbit of the earth, where he would land after 17 orbits. The NORAD Space Detection and Tracking System, which went into operation formally on July 7, maintains a continuous catalog of man-made objects in space.

Injection Guidance

(CONTINUED FROM PAGE 29)

Guidance in this system is open loop; that is, there is no specific measurement of velocity vector or position. The accuracy of guidance is more dependent upon the predictability of the forces which act on the vehicle than the performance of the components in the system. Systems such as this have been used to inject satellites into orbit, but are not satisfactory for a problem requiring any sophistication in the definition of the orbit to be achieved.

Guidance from ground equipment is accomplished by measuring the trajectory of the vehicle with ground-based radar and controlling it to a desired flight path on the basis of these measurements. The actual command signals are generated in the ground-based equipment. An automatic target-tracking radar provides the measurement of vehicle position. A computer calculates error signals based on deviations from the desired trajectory. A command link transmits discrete commands to the airborne control system. Because of the necessary lag between actual measurement and command, additional airborne equipment is frequently required to assure satisfactory dynamics in the guidance loop.

An on-board transponder permits initiation of a radioed cutoff command by the same general method used for injecting the German V-2 into its ballistic trajectory; this method, which applies the Doppler principle, is called the "Wolmann cutoff method." A radio transmitter of frequency f_0 is located at the launch site. The frequency of the signal as received at the rocket is $f_R = f_0 - \Delta f$, due to the "down Doppler" shift caused by the rocket's receding at a line-of-sight velocity, V_R. Doppler's equation usually is expressed to a first order approximation as $f_R \cong f_0 - f_0 V_R/c$, from which, if c is the velocity of light (assumed constant), $V_R \cong c\Delta f/f_0$.

The transponder in the rocket doubles the received frequency and retransmits (at a frequency of $2f_0 - 2\Delta f$) to the ground station. Of course, during the return trip, the signal accumulates another Doppler shift, and is received by the ground station as $f_{RG} = 2f_0 - 4\Delta f$.

By heterodyning this with the second harmonic of the ground transmitter, the $4\Delta f$ shift (proportional to velocity) is recovered through a filter. Having required $4\Delta f$ for a desired V_R of $(4\Delta f) \cong (4f_0/c)\ V_R$, an oscillator tuned to represent the *desired* V_R beats against the received Doppler shift. When the beat note approaches zero, the line-of-sight velocity is approaching V_R, whereupon a radio command for cutoff can be initiated. If the rocket's vector velocity is directly away from the ground station at that instant (controlled by pitch-over commands to the autopilot), the cutoff velocity will equal the desired V_R quite closely. Actually, a throttle-back reduces thrust as the desired velocity is approached, thus permitting a vernier action to increase precision just before complete cutoff.

Installation of a three-axis stabilized inertial measuring unit in the vehicle makes possible the use of radio-command systems which operate at lower frequencies. This reference platform provides attitude signals with respect to a known coordinate frame and permits monitoring of the vector acceleration in these coordinates. Addition of a guidance computer to the airborne system permits it to issue appropriate autopilot commands and thrust-cutoff signals in response to radioed velocity-to-be-gained signals.

The additional time allowed the ground station may be utilized to smooth the tracking data and compare a prediction of the observed with the desired motion. The resulting correction is transmitted as three components of velocity-to-be-gained in the platform coordinate systems. A future time execution by the airborne system may also be commanded.

Extending Radio Control

These radio-control methods are inherently limited to line-of-sight range from the guidance radar. However, causing the vehicle to pass through a succession of strategically located guidance beams along the intended subtrack could open up the possibility for wide application of the method to space missions. Such guidance would be particularly useful for missions where the airborne hardware must be held to a minimum. It is a relatively expensive trade-off, however, because

of the cost of multiple ground stations which give adequate coverage for any variety of trajectories.

Radio-guidance hardware has been developed for several such systems during the past 15 years. The basic errors of radio systems tend to decrease with increasing operating frequency; this makes eventual operation at coherent optical frequencies an extremely attractive possibility. Although coherent optical guidance systems still are in the research phase, the next 15 years may bring remarkable strides in remote guidance.

While the totally remote radio guidance usually is not adequate for sophisticated space missions, a closed-loop radio system successfully guided Tiros I into orbit with an altitude error of 1 n.mi. (See "Guidance of Tiros I" by Myers and Thompson in the May 1961 *ARS Journal*, page 636.)

An inertially-aided system is only a short step from the completely self-contained system. Increased airborne computer capacity permits it to be programmed to do nearly everything the ground-based computer could do. The entire injection program can be stored in the airborne computer. The computer obtains its position and velocity by numerical integration of the power track indicated by the inertial platform's sensors. It uses the dead-reckoning information so obtained to calculate its ballistic motion, through numerical time integration of the equation of ballistic motion. Only the initial conditions and constants loaded into storage prior to launch are required from the ground-based computer, after the airborne computer has been programmed.

The inertial platform maintains a coordinate system which is stable in space. The acceleration is measured in this coordinate frame and provides a continuous indication of forces affecting the trajectory of the vehicle. These measurements provide the basic information from which guidance errors are generated by the airborne computer. There are a number of methods of combining these measured data, but all are aimed at achieving a certain velocity vector and altitude combination.

This type of guidance system allows a greater flexibility in selecting the initial conditions desired for an orbital or space mission. Because it is closed-loop—in that it actually measures the quantities it is attempting to control (as contrasted to the minimum injection-guidance system)—it is not necessary to predict force effects. As a self-contained system, it is not subject to the geographic (or line-of-sight) limitations of the ground-control guidance systems. The accuracy of the guidance mission is directly related to the performance of the airborne equipment. Its performance degrades with time, since no measurements relative to a known point in space are available after launch, in contrast to the radio-guidance system. It does require a greater amount of airborne equipment, penalizing the boost required of the vehicle to that extent.

The potential of this type of guidance system has yet to be fully exploited in providing injection guidance for orbital and space missions. Such equipment, however, has already been used on several of the same boosters which have been used to place payloads in orbit. The photo on page 29 shows the airborne hardware which make up such a guidance system, in this case for the Centaur space vehicle.

Advantage of Optics

A further step which retains the flexibility inherent in a self-contained system, but regains the long-term precision of systems referenced to a fixed point in space, requires the addition of airborne hardware. Optical equipment which tracks planets and stars can provide this reference to a fixed point.

The utility of such a combination is questionable when considering the injection-guidance problem alone. The three methods previously mentioned provide solutions which cover the gamut of injection-guidance problems. It is only as guidance requirements beyond those for earth-orbit injection are imposed that such a system can be considered necessary. Economies in payload are realized if this same equipment can satisfy midcourse or even terminal guidance requirements as well.

The human operator already has been incorporated into the guidance and control system. Man operating a set of controls is, however, not an independent method of injection guidance. He only serves to enhance the reliability of the automatic guidance system by providing redundant decision making and manipulation.

Any new injection-guidance concept should have the capability of being tested by itself in the actual environment before the human operator is introduced as a part of the system. The injection-guidance system is then complete without the operator. His role is not an integral part of the guidance concept, and his actions serve only to contribute to the probability of his safe survival.

This is the pattern which has been established by the recent Mercury flights. The astronauts contributed to guidance and control during flight; however, the mission itself had been accomplished a number of times without their contribution. This pattern, in all probability, will continue for future orbital and space missions.

Injection-guidance requirements need not progress beyond the conceptual capabilities of existing guidance-system designs. Programmed-attitude, radio-guidance, and inertial-guidance systems which can guide a payload into orbit already exist. No new concepts are required to satisfy present or reasonable future needs for injection.

Inertial guidance is the most recent of these three forms, and the most promising. Because it is a closed-loop system, it provides significantly better performance than the programmed reference system. Because it is self-contained, it is not limited to line-of-sight trajectories. Inertial-guidance-system designs with enough flexibility to handle the full scope of injection-guidance requirements already have been built and are in the early stages of testing.

Progress will not stop at the point of conceptual success. Competitive pressure will foster more stringent requirements and the state of the art will continue to advance. This advance will concentrate in four areas: Reliability, performance, miniaturization, and simplification of countdown procedures. Injection guidance for a complicated space mission is not limited to a short period of time during which a continuous high level of thrust is applied. In fact, to bring a vehicle to a particular position with a certain velocity vector may require many hours of operating time. Both reliability and performance are penalized as these time periods for operation are extended.

Reliability in our present equipment has as its ultimate limitation wear at mechanical contacts and performance degradation which is a result of this mechanical wear. It is true, a higher percentage of failures are associated with the electronics of the guidance system, and a direct attack is needed to improve the reliability of electronics. Major progress toward component reliability has been made through control of the basic materials during manufacture. Additional benefits accrue from environmental protection of the resulting components during the pre-use phases of transportation and storage. Some of the ultimate mechanical-wear limitations already are yielding to developments which provide electric and magnetic suspension between the relative moving parts.

The flexibility available in guidance systems of existing design results, to a considerable extent, from the use of digital computation for the guidance solution. Performance im-

provements in injection guidance are, because of this, also facilitated, in that improved computing performance is available at the designer's discretion without further development. Advancements in performance ability are, then, a function of improvements in the sensing elements. Sensing-element improvements already are available in the laboratory and will provide greater accuracy in future systems.

Significant steps in miniaturization already are on the horizon with the advent of deposited circuits of several types. An important concomitant benefit is realized here in the reduction of power requirements and, hence, the size of power storage and processing equipment.

Many space missions require a flexibility at the launch site which is not inherent in the present countdown procedures. The possibility of arriving at a particular destination may, in these cases, depend upon the possibility of rapidly re-determining the injection-guidance trajectory and meeting a specific firing time with a relatively small tolerance. Improvements in this problem area already are available to some extent through the use of more sophisticated guidance computations in the airborne equipment. A second category of improvement relates directly to the reliability problem, in that precise readiness for launch may require extended periods of prelaunch operation.

In summary, we may say that the general configuration of the injection-guidance system will not change appreciably. The method in which it is mechanized will make a rather significant transition. Sensing elements are already being tested in the laboratory that feature moving parts with no mechanical contact with the rest of the system. Suspension of these spinning elements in electric or magnetic fields improves reliability and performance. Electronic circuits which are appropriate combinations of molecular depositions will reduce size and power by an order of magnitude. Although this constitutes a complete internal difference, the concept and functional interface will not change. ♦♦

Advanced Sidereal Test Stand Planned for NASA-Marshall SFC

The most advanced form of sidereal table for testing gyroscopes and other inertial components, one that will give information on table position in digital form with an accuracy of 0.1 arc second, will be developed for Marshall Space Flight Center by the J. W. Fecker Div. of American Optical Co. under a recently awarded NASA contract for $146,650.

INDEX TO ADVERTISERS

ADVERTISING REPRESENTATIVES

NEW YORK: D. C. Emery & T. J. Harford
400 Madison Ave., New York, N.Y.
Telephone: Plaza 9-7460

LOS ANGELES: James C. Galloway & Co.
6535 Wilshire Blvd., Los Angeles, Calif.
Telephone: Olive 3-3223

CHICAGO: Thomas M. Byrne Jr.
2316 Sherman Ave., Evanston, Ill.
Telephone: 869-1831

ENGINEERS: you can probe the propulsion future in

CONNECTICUT or FLORIDA

EAST HARTFORD ENGINEERING FACILITY

WIDE-RANGE OPPORTUNITIES—Pratt & Whitney's main plant facility in East Hartford, Connecticut, is expanding its operations in advanced research and development projects and long-range planning. In addition to our established capability in the flight propulsion field, we are exploring the fringe areas of technical knowledge in aerospaceplane propulsion systems, magnetohydrodynamics, thermionic, and thermo-electric conversion; solar energy conversion, supersonic combustion, fuel cells, and nuclear power for military, space, marine, and industrial applications. Other engineering studies are being conducted on advanced turbojets and turbofans including regenerative turbine engines and supersonic transport propulsion systems.

In support of our engineers we have the world's largest privately-owned installation for the development-testing of advanced powerplant and high-power rotating machinery as well as the latest in automatic data acquisition systems and computer facilities.

EDUCATIONAL ADVANCEMENT—Engineers at Pratt & Whitney Aircraft have an unusually fine opportunity to continue their formal education under the United Aircraft Corporation Graduate Education Program with full tuition costs being paid by the company directly to the institutions involved for those who successfully complete the requirements for advance degrees. Excellent courses are offered at the Rensselaer Polytechnic Institute Hartford Graduate Center located a few miles from our East Hartford Plant as well as at other fully accredited schools in Connecticut.

EXCELLENT LIVING CONDITIONS—Pratt & Whitney Aircraft is ideally located in picturesque New England, midway between Boston and New York. Year round recreational facilities abound at the seashore, lakes and mountains.

Openings exist at all levels of experience for engineers and scientists who want to work as part of a team dedicated to maintaining Pratt & Whitney's position of leadership in the future.

Please submit your resume, including minimum salary requirements, to:

MR. P. R. SMITH, OFFICE 50
PRATT & WHITNEY AIRCRAFT
410 MAIN STREET
EAST HARTFORD 8, CONNECTICUT

FLORIDA RESEARCH AND DEVELOPMENT CENTER

From out of Florida comes the power to put man into the vast outer reaches of space or propel him at record speed in the atmosphere. The locale is the seven-thousand acre site of Pratt & Whitney Aircraft's Research and Development Center at West Palm Beach, Florida.

ENGINEERING PROGRESS—Within the few short years since its activation, the Center's creative achievements have assumed truly significant proportions. Today the material results are exemplified by our current engineering projects which include hydrogen fueled rocket engines and advanced supersonic aircraft powerplants. Our engineering accomplishments and versatility have well equipped us for challenging new assignments in developing new concepts and techniques in today's space age. Advanced studies in applied research include space vehicle mission analysis, advanced propulsion systems studies, advanced fabrication techniques, advanced control systems, and studies in the cryogenic field.

EXCELLENT FACILITIES—The adequate support of such engineering feats demands the finest of facilities. The Florida Research and Development Center is one of the world's most complete technological facilities devoted to aerospace propulsion. These facilities provide for the accelerated development of advanced rocket motors, high Mach turbojet engines, full-scale rocket components, fuels and fuel handling. And further assisting our engineers are comprehensive automatic data acquisition and processing systems, including the latest in computing facilities.

IDEAL ENVIRONMENT—The calibre of men we seek is typified by Pratt & Whitney engineering advances. We invite communications from engineers and scientists who would enjoy working in a vacation climate. Just a few minutes from the Center are pleasant communities providing year-round golf, water skiing, fishing, boating, swimming or just plain sunning on golden beaches.

Please submit your resume, including minimum salary requirements, to:

MR. J. W. MORTON, OFFICE 50
PRATT & WHITNEY AIRCRAFT
WEST PALM BEACH
FLORIDA

All replies will be handled promptly and in complete confidence.

Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORP.

AN EQUAL OPPORTUNITY EMPLOYER.